2. EFFLUENT FATE AND TRANSPORT MODELING

A hydrodynamic model of the Potomac River was developed to simulate both river flow and the suspended solids discharge plume from the Washington Aqueduct outfalls. The primary objective of the modeling was to determine acute and chronic dilution factors as a function of effluent loading and river flow. A secondary goal was to model the fate of the released solids as they are transported downstream. The modeling used the Surfacewater Modeling System (SMS), which includes the U.S. Army COE – supported models RMA2, RMA4, and SED2D (see Section 2.2). To provide the necessary data for model development and calibration, field studies were performed including:

- A bathymetry survey of this river segment to provide cross-sectional geometry for model development

- Dye-tracer and turbidity plume mapping surveys during solids discharge events at Dalecarlia (Outfall 002) and Georgetown Reservoir (Outfall 003) to provide data sets for model calibration

A summary discussion of the results of the field surveys is presented and Section 2.1 and a summary discussion of the development of the Potomac River model is presented in Section 2.2. A more detailed discussion of the field surveys and model calibration is provided in Appendix B. The application of the calibrated model to simulations addressing the fate of the released solids and mixing zone issues is provided in Section 2.3.

2.1 FIELD STUDIES

A bathymetry survey of the Potomac River area included in the model was performed on 6-7 April 2000. During the same two days, cross-sectional velocity measurements were collected along two transects. At Outfall 003 from Georgetown Reservoir, a dye-tracer plume mapping survey was performed on 2 May 2000 and a turbidity mapping survey was performed on 3 May 2000 in conjunction with a suspended solids discharge event. At Outfall 002 from Dalecarlia Basin, a dye-tracer plume mapping survey was performed on 24 May 2000 and a turbidity mapping survey was performed on 25 May 2000 in conjunction with a suspended solids discharge event from Dalecarlia Basin 3. During the 3 May and 25 May 2000 turbidity studies, river and effluent water samples were collected that were analyzed for total and dissolved aluminum and TSS. Each of these field studies is addressed below.

2.1.1 Bathymetry Survey

A bathymetry survey of the Potomac River was conducted during 6-7 April 2000 extending for a 7.5-km distance from Memorial Bridge, upstream to Chain Bridge. A more detailed discussion of the bathymetry survey is provided in Appendix B.1.1. During these two days, depth data were measured along a total of 46 transects, which are illustrated in Figure B.1-1. The survey boat was equipped with a depth sounder and a global positioning system (GPS). The positioning and depth data were recorded at a 1-second interval to a laptop computer used onboard the survey boat as a data logger.

Water elevations during the bathymetry survey were recorded using an ENDECO 1029 water level recorder. The water level recorder was deployed in the vicinity of Outfall 003. The observed water elevations were used to adjust the depth measurements recorded during the surveys to mean low water (MLW).

The bathymetry data used in the model was augmented with hydrographic survey data collected by the National Ocean Service (NOS). In 1976 and 1977, NOS conducted surveys H9478 and H9488, which covered portions of the area included in the Potomac River model. In general, the bathymetry data measured during the 6-7 April survey provided adequate representation of the site. The NOS data were used to augment the survey data in the vicinity of Roosevelt Island and the downstream section of the model between Roosevelt Island and Memorial Bridge.

2.1.2 Cross-Sectional Velocity Survey

On 6 and 7 April 2000, cross-sectional velocities were measured along two transects downstream from Outfall 003. The velocity survey was performed to provide data to use during model calibration to adjust channel friction coefficients. A more detailed discussion of the cross-sectional velocity survey is provided in Appendix B.1.2.

The velocity data were measured along two transects: Transect B3 located approximately 400-m downstream of Outfall 003 and Transect B4 located approximately 1,700-m downstream in a broader section of the river (Figure B.1-1). The velocity surveys on both 6 and 7 April 2000 took place during an ebb tide. At Transect B3, measurements were made at five stations spaced evenly across the river. At Transect B4, 6-7 stations were used. At each station, velocity readings were made at 0.6-m (2-ft) intervals down to a 3.7-m (12-ft) depth. The velocity data are provided in Table B.1-1. At Transect B3, vertical average velocities were typically 10-20 cm/sec off-channel towards the left bank, and maximum vertical average velocities of 42-59 cm/sec were present in the channel. At Transect B4, the velocity distribution was more uniform across the river and was typically 20-30 cm/sec away from the near-shore stations.

The velocity survey data was used during model calibration to adjust the model's channel friction coefficients, which determine the lateral velocity distribution. The velocity data will be displayed in figures as part of model calibration in Section B.2.2.

2.1.3 Field Methodology and Physical Site Conditions

Basin/reservoir cleanings are typically a two-step process. The overlying water is released to the river on the first day (usually a 6-14 hour period), and then the solids are hosed or pushed out on the morning of the second day (usually a 3-4 hour period). Plume mapping surveys were performed at Outfalls 002 and 003 in conjunction with suspended solids discharge events. On the day preceding the reservoir clean-out, the overlying water in the reservoir is discharged to the river to provide access. The dye-tracer studies were performed during this 6-14 hour drawdown period. The dye study can only be performed during the reservoir drawdown when relatively clean water is being discharged because the suspended sediment masks the fluorometer reading at high TSS values and provides a false positive at lower TSS levels. During the dye study, Rhodamine WT dye was injected into the discharge flow for an approximately 6-hour period. The discharge flow present on the day of the reservoir drawdown was typically several times higher than the flow used during the actual solids clean-out event. The release of dye for a several hour period allows the resulting dye distribution in the Potomac River to simulate both the build-up and subsequent diffusion of the suspended solids release. During the surveys, the plume mapping transects were repeated approximately every 1.5 to 2 hours. In addition, during each dye and turbidity study, at least one full mapping survey was performed after the discharge was turned off.

The transects used during the plume mapping surveys are listed in Table 2.1-1 and illustrated in Figure 2.1-1. Table 2.1-1 includes the distance of each transect downstream from Outfalls 002 and 003. During the 2-3 May 2000 surveys at Outfall 003 (Georgetown Reservoir), Transects 7 to 20 were used. Transect 7 was the upstream background transect, and Transect 8 was located at Outfall 003. During the 24-25 May 2000 surveys at Outfall 002 (Dalecarlia Basin), Transects 1 to 20 were used, excluding Transects 8 and 9, which were closely spaced specifically for the previous Outfall 003 survey.

The following section summarizes the field methodology used during the surveys. A more detailed discussion is provided in Appendix B.1.3.

During the dye surveys, a 20-percent solution of rhodamine WT dye was injected into the reservoir outflow using a precision metering pump. The dye plume mapping surveys were performed using a boat equipped with a Turner Designs Model 10 fluorometer set up in the flow-through mode. The fluorometer sampling hose was mounted to a strut on the side of the boat at a fixed 0.3-m depth. The fluorometer readings were recorded at 1-second intervals with a Campbell CR10 data logger as the boat moved continuously along the survey transects. The survey boat was also equipped with a GPS system that also recorded continuously at a 1-second interval. The fluorometer was calibrated at the end of the survey day using site water for the calibration dilutions. The resulting instrument calibration was used to convert the fluorometer reading to concentrations in part per billion (ppb).

The turbidity plume mapping surveys were performed in a similar manner as the dye survey by continuously recording data as the boat moved along survey transects. A Coastal MacroLite with an OBS-3 turbidity sensor was mounted on a fixed strut at a 0.3-m depth. The turbidity values were recorded continuously at 2-second intervals to a lap-top computer. The survey boat also contained a GPS system that recorded at 1-second intervals.

An ENDECO 1029 water level recorder was deployed in the vicinity of Outfall 003 for the duration of the dye and turbidity plume mapping studies.

2-3 May 2000 (Outfall 003) – Georgetown Reservoir

On 2 and 3 May 2000, both the dye and turbidity studies started during an early ebb tide and the last survey was performed near or just following low slack water. The tide heights during the dye and turbidity plume mapping surveys are provided in Figures B.1-5 and B.1-6 which also indicate the duration of the discharge event and the times of each survey. Potomac River flows at the USGS gage at Little Falls are displayed in Figure B.1-7 for the 2-3 May 2000 period. During the 2 May 2000 dye study, river flow decreased from approximately 305 cms to 300 cms, and during the 3 May 2000 turbidity study, river flow decreased from 272 cms to 266 cms.

24-25 May 2000 (Outfall 002) – Dalecarlia Basin 3

On 24 and 25 May 2000, the dye and turbidity studies started during an early flood tide and the last survey was performed during the following ebb tide. It should be noted that at the Potomac River flow conditions associated with these studies, the river current does not reverse direction during a flood tide, but only slows up. The tide heights during the dye and turbidity plume mapping surveys are provided in Figures B.1-8 and B.1-9, which also indicate the duration of the discharge event and the times of each survey. Potomac River flows at the USGS gage at Little Falls are displayed in Figure B.1-10 for the 24-25 May 2000 period. River flows during the 24-25 May 2000 period were significantly lower than during 2-3 May 2000. During the 24 May 2000 dye study, river flow increased from approximately 160 cms to 170 cms, and during the 25 May 2000 turbidity study, river flow increased from 190 cms to 215 cms.

2.1.4 Water Chemistry Data

River Water Chemistry Data

Surface water samples were collected as part of the turbidity plume mapping surveys on 3 May 2000 at Outfall 003, and 25 May 2000 at Outfall 002. These samples were analyzed for total suspended solids (TSS), dissolved aluminum, and total aluminum. In addition, a turbidity reading was made onboard the boat at the time of sample collection.

The water chemistry samples were collected along the same transects used for the turbidity mapping surveys (Figure 2.1-1). However, because of the time required to collect and process each sample, only approximately every-other transect was employed. On 3 May 2000 (Outfall 003), Transects 7, 9, 11, 12, 13, 14, and 16 were used. On 25 May 2000 (Outfall 002), Transects 1, 4, 6, 9, 12, and 14 were used. A left and right sample was collected at the upstream Transects 1, 4, and 7 where the river is narrower, and a left, middle, and right sample was collected downstream where the river is wider. At each outfall, three sets of water chemistry samples were collected during the period that the four turbidity plume mapping surveys were performed. A total of 43 water samples were collected at river stations during the 3 May 2000 survey, and a total of 42 water sample were collected during the 25 May 2000 survey.

The water chemistry results from the 3 May 2000 turbidity study at Outfall 003 (Georgetown Reservoir) are provided in Table B.1-3 and the results for the 25 May 2000 study at Outfall 002 (Dalecarlia Basin 3) are provided in Table B.1-4. These tables provide concentrations for dissolved and total aluminum, TSS, and turbidity. A more detailed discussion of the water chemistry data is provided in Appendix B.1.5, including the relationship between dissolved and total aluminum (Figure B.1-11) and between total Al and TSS (Figure B.1-12). The water chemistry data indicates that dissolved Al in the sampled surface waters has a concentration of approximately 100-150 μg/L, which does not noticeably increase as the total Al concentrations increase from approximately 500 μg/L to 3,000 μg/L. Both the Outfall 002 and Outfall 003 studies display a linear relationship between total Al and TSS, with total Al increasing from approximately zero to 2.5 mg/L (2,500 μg/L), as TSS increases from approximately zero to 30 mg/L.

Relationship Between TSS and Turbidity

The relationship between TSS and turbidity was examined to provide a method to convert the readings from the probe used on the survey boat during the turbidity plume mapping surveys to TSS concentrations. The relationship between TSS and turbidity displayed by the 85 water chemistry samples collected during the 3 and 25 May 2000 surveys was evaluated. Figure 2.1-2 indicates that a linear relationship exists with the following regression equation ($R^2 = 0.76$):

$$\text{TSS (mg/L)} = 1.541\ \text{Turbidity(NTU)} - 2.40$$

The above equation relates turbidity as measured by the Hach turbidity meter on the water chemistry sampling boat to TSS. An additional data set was examined to relate values obtained from the turbidity probe used on the plume mapping boat to the Hach meter measurements. During the turbidity surveys, 13 grab samples were collected next to the turbidity probe on the plume mapping boat, which were then processed with the Hach turbidity meter. Based on these samples, the relationship between turbidity as measured by the turbidity probe and the Hach meter is provided in Figure B.1-14. The relationship between the two turbidity sensors was combined with the relationship between turbidity and TSS to provide an equation to convert the survey turbidity data to TSS. An examination of the turbidity data during the two surveys indicated a slight shift in the intercept for NTU resulting in the following expressions:

$$\text{TSS (mg/L)} = 1.541\ \text{Turbidity} - 20.9 \quad \text{3 May 2000 (Outfall 003)}$$
$$\text{TSS (mg/L)} = 1.541\ \text{Turbidity} - 17.8 \quad \text{25 May 2000 (Outfall 002)}$$

In the above equations, turbidity is the value measure by the turbidity probe on the plume survey boat.

Effluent Water Chemistry Data

Effluent water chemistry samples were collected periodically from the reservoir discharge during the 2-3 May and 24-25 May 2000 studies. Similar to the river water chemistry samples, the effluent samples were analyzed for TSS and total and dissolved aluminum. The results of effluent water chemistry samples collected during the reservoir drawdown and during the suspended solids discharge on the following day are provided in Table B.1-5. At Outfall 003

(Georgetown Reservoir), TSS values were <2.5 mg/L during the drawdown phase and total aluminum concentrations ranged from 187 to 233 μg/L. During the solids discharge on the following day, TSS values ranged from 4,700 mg/L to 12,300 mg/L, with two additional values of less than 1,000 mg/L that most probably are associated with temporary lulls in the clean out. During the solids release on 3 May 2000, total effluent aluminum concentrations ranged from 26 to 1,300 mg/L.

At Outfall 002 (Dalcarlia Basin), TSS concentrations were low during most of the 24 May 2000 basin drawdown (<5 mg/L), although TSS increased near the end as the basin elevation reached bottom. During the solids discharge on the following day (25 May 2000), TSS concentrations ranged from 4,600 to 16,500 mg/L before dropping off to 235 mg/L at the end of the discharge event. Total aluminum concentrations during the discharge event ranged from 1,020 to 1,810 mg/L and decreased to 28.1 mg/L at the end.

2.1.5 Particle Size Distribution

The size of the particles in the effluent is an important factor in the modeling of solid's transport and deposition in the Potomac River. As discussed below, particle size distributions were determined using several methods to address the characteristics of the floc that is produced in the water treatment process.

Standard ASTM Particle Distribution

During the suspended solids discharge events, sediment samples were collected from the bottom of each reservoir. On 3 May 2000, a sediment sample was collected from Georgetown Reservoir, and on 25 May 2000, two samples were collected from Dalecarlia Basin 3. Each sample was a composite of material collected from two locations. A particle size analysis was performed on each sample and the results are provided in Table B.1-6. The two Dalecarlia samples were very similar and an average distribution was calculated. Based on particle size, the Georgetown sample was 50.2 % sand, 31.6% silt, and 18.2% clay. The averaged Dalecarlia sample contained more sand and less clay and silt than the Georgetown sample. The Dalecarlia fractions were 81.3% sand, 12.4 % silt, and 6.3% clay. Since the water for both reservoirs is drawn from the same location in the Potomac River, there is no apparent reason for the particle size fractions to differ except possibly for natural seasonal variation over the period of time since the previous clean out. The Georgetown and averaged Dalecarlia data were combined to provide a composite particle size distribution that is considered to be representative of typical conditions. The composite sample was 65.7 % sand, 22.0 % silt, and 12.3 % clay (Table B.1-6).

Particle Characteristics of Floc

The composite particle size distribution for sediment samples from the Georgetown and Dalecarlia Reservoirs does not reflect the presence of the floc resulting from the addition of alum in the treatment process. The ASTM hydrometer and sieve methodology for determining particle size uses sodium hexametaphosphate as a de-floccing agent. The resulting size distribution, therefore, reflects the underlying particles, but not the aggregated particles forming the floc. On 5 March 2001, an additional sediment sample was obtained from the bottom of a Dalecarlia basin during a clean-out event. This sample was subject to a hydrometer test without the use of a de-floccing agent. This test is described in Appendix B.1.6.

In a standard hydrometer test, the particle velocity is related to a particle diameter according to Stokes' law and assuming a spherical particle with a density associated with the dry sample. However, a floc is composed of a collection of particles and the floc also has a very high moisture content. Tambo and Watanabe (1979) presented a paper on the physical characteristics of flocs including results from experimental studies with aluminum flocs. The paper provided a settling velocity equation for a non-spherical aluminum floc particle and a relationship for floc density as a function of floc diameter (see Appendix B.1.6). Using this information, floc diameters associated with the settling velocities resulting from the hydrometer test were calculated and provided in Table B.1-7. The range of settling velocities in Table B.1-7 corresponds to a range of floc diameters of approximately 0.03 to 0.4 mm. A spherical sand or silt particle would require a diameter 4-10 times smaller in order to posses a similar settling velocity.

The particle characteristic data presented in this section will be analyzed further in Section 2.2.4 when constructing particle distributions for model simulations.

2.1.6 Plume Surveys at Outfall 003 (Georgetown Reservoir)

A dye-tracer plume mapping study was performed at Outfall 003 on 2 May 2000 while the Georgetown Reservoir was being drawn down. The following day (3 May), a turbidity plume mapping study was performed during and for several hours after a suspended solids discharge event. As discussed in Section 2.1.3, both studies took place primarily during an ebb tide.

Dye Plume Mapping Surveys (2 May 2000)

On 2 May 2000, a 20-percent solution of Rhodamine WT dye was injected into the reservoir outflow starting at 0749 hours and continued until 1406 hours. During the period of dye injection, three effluent samples were collected at the concrete outfall structure near the river at approximately 1-hour intervals and analyzed for discharge dye concentration. The discharge flow was calculated from the dye injection rate and the observed effluent concentrations (Table B.1-8). The average discharge flow based on the three samples was 3.46 cms (79 mgd).

The transects used during the dye survey were listed in Table 2.1-1 and illustrated in Figure 2.1-1. Outfall 003 is located at Transect 8 and Transect 7 (150-m upstream of Outfall 003) was used for background. The times of the five dye plume mapping surveys are summarized in the following table.

2 May 2000 – Outfall 003

Survey	Time (hrs)
Dye Injection	0749 - 1406
Survey 1	0820 – 0915
Survey 2	1009 – 1117
Survey 3	1134 – 1235
Survey 4	1338 – 1448
Survey 5	1509 - 1631

The dye concentration data recorded along each transect are provided in Appendix Figures A.1-1 to A.1-14 for Transects 7 to 20. The minimum, maximum, and mean dye concentrations along each transect are summarized in Table B.1-9. An examination of Table B.1-9 indicates that the leading edge of the dye plume arrived downstream at Transects 10, 13, and 16 respectively during the first three surveys. By survey 5, dye had just arrived at Transect 20 (5.05 km downstream from Outfall 003), 8.5 hours after the initiation of dye injection. A more detailed discussion of the results of the 2 May 2000 dye study at Outfall 003 is provided in Appendix B.1.7.

A plume map displaying dilution contours was constructed from the dye survey data for the 500-m region downstream from Outfall 003 (Transects 8-11). The dilution contours were based on the average dye concentrations during surveys 2 and 3, which were performed before the termination of dye injection. The discharge dye concentration during this period was 20.7 ppb based on an average of survey values in the vicinity of the discharge. The resulting dilution contour map (Figure 2.1-3) indicates that the contour for a dilution factor of 5 extended 120 m, and a dilution factor of 10 extended approximately 380 m. The arc of the factor of 5-dilution contour delineates the approximate offshore extent of the eddy that was located downstream of the outfall. A dilution factor of 20 extended beyond Transect 11, which was 480-m downstream.

Turbidity Plume Mapping Surveys (3 May 2000)

On 3 May 2000, the suspended solids discharge event lasted for 3.5 hours, from approximately 1000 hours to 1330 hours. The effluent samples collected and analyzed for aluminum and TSS were previously presented in Table B.1-5. Three of the effluent samples had TSS concentrations that varied between 4,500 mg/L and 12,300 mg/L. Between 1120 and 1250 hours there appeared to be a lull in the clean-out and TSS values were temporarily less than 1,000 mg/L.

The transects used during the turbidity surveys were listed in Table 2.1-1 and illustrated in Figure 2.1-1. The times of the four turbidity mapping surveys are summarized in the following table.

3 May 2000 – Outfall 003

Survey	Time (hour)
Clean out	1000 - 1330
Survey 1	1018 - 1050
Survey 2	1118 - 1222
Survey 3	1301 - 1352
Survey 4	1527 - 1622

Outfall 003 is located at Transect 8 and Transect 7, 150-m upstream of Outfall 003, was used for background. During the surveys, transects were performed through Transect 17, just upstream of Key Bridge. The turbidity data recorded along each transect are provided in Appendix Figures A.2-1 to A.1-11 at Transects 7 to 17. The relationship between turbidity and TSS developed in Section 2.1.4 was used to transform the turbidity survey data into TSS. The TSS values are presented in the appendix figures by the addition of a second axis. The resulting minimum, maximum, and mean TSS concentrations along each transect are summarized in Table B.1-10.

Background TSS levels at Transect 7 were typically 6-8 mg/L during the 4 surveys (Figure A.2-1). At outfall 003 (Transect 8), a maximum value of 2,164 mg/L was measured during survey 2. At Transects 9 and 10, maximum TSS concentrations of 43-86 mg/L were present during surveys

1-3 and values decreased by survey 4, which was started approximately 2-hours after the clean-out was completed.

Downstream of Transect 12 (Figures A.2-6 to A.2-11), there were no clearly evident TSS plume features. This contrasts with the previous day's dye survey when a plume was present with maximum concentrations along the near shore, extending both laterally and in a downstream direction. A more detailed description of the turbidity plume results is provided in Appendix B.1.7.

A contoured map of TSS values is provided in Figure 2.1-4 for the 450-m reach from Outfall 003 to Transect 11. The data set used for the figure is a composite of the highest turbidity values along each of these four transects during the four surveys (Figures A.2-2 to A.2-5). The turbidity values were converted to TSS using the relationship developed in Section 2.1.4. The resulting TSS values were 2,000 mg/L at the outfall, decreasing to maximum values of 85 mg/L at Transect 9 (70 m), 48 mg/L at Transect 10 (200 m), and 43 mg/L at Transect 11 (480 m). The 48-mg/L TSS value at Transect 10 (200 m) corresponds to a dilution factor slightly above 40:1. The high suspended loads discharged from Outfall 003 are dissipated in the river at a higher rate than would be indicated by the dye study. In Figure 2.1-3, the maximum dye concentration at Transect 10 corresponded to a dilution factor of 10:1, a factor of four smaller than that determined using the TSS plume data. The increased dilution observed in the turbidity survey may result in part from settling and stratification of TSS in the water column. The turbidity probe used for the plume mapping surveys was mounted in the upper portion of the water column. It is likely that higher TSS concentrations were present in the lower portion of the water column.

2.1.7 Plume Surveys at Outfall 002 (Dalecarlia Basin)

A dye tracer plume mapping survey was performed at Outfall 002 on 24 May 2000 while the Dalecarlia Basin was being drawn down. The following day, 25 May 2000, a turbidity plume mapping survey was performed during and for several hours after a suspended solids discharge event associated with the basin clean out. As discussed in Section 2.1.3, both studies primarily took place during a flood and early ebb tide.

Dye Plume Mapping Surveys (24 May 2000)

On 24 May 2000, a 20-percent solution of Rhodamine WT dye was injected into the outflow from Dalecarlia Basin 3 starting at 0809 hours and continuing to 1415 hours. During the period of dye injection, 11 effluent samples were collected at a manhole several hundred meters from the injection point at approximately 30-minute intervals. The dye injection rate determined from the scale readings and the measured effluent concentrations are provided in Table B.1-11. The discharge flow was calculated from the dye injection rate and the observed effluent concentrations (Table B.1-11). The average discharge flow from the 11 samples was 1.75 cms.

The discharge flow from Dalecarlia was also calculated based on the observed drawdown of Basin 3. Between 0805 hours and 1340 hours, the basin's elevation decreased 5.92 m (19.42 ft). This level change, coupled with the basin area of 5,888 m^2 yields an average discharge flow of 1.73 cms (39.6 mgd). This discharge flow is in excellent agreement with the 1.75-cms value calculated from the dye injection rate and the 1.73-cms flow value was used in subsequent analysis.

The transects used during the dye surveys were listed in Table 2.1-1 and illustrated in Figure 2.1-1. The times of the five dye plume mapping surveys are summarized in the following table.

24 May 2000 – Outfall 002

Survey	Time (hrs)
Dye Injection	0809 – 1415
Survey 1	0842 – 0902
Survey 2	0950 – 1029
Survey 3	1107 – 1249
Survey 4	1338 – 1509
Survey 5	1555 – 1728

Outfall 002 is located approximately 520-m upstream from Transect 1 in a relatively narrow and high velocity portion of the river. Transect 1, just below Chain Bridge was considered to be the farthest upstream location that was safe for performing lateral plume mapping surveys. Each survey was performed progressively farther downstream and surveys 4 and 5 were performed to Transect 20 at Memorial Bridge. The dye concentration data recorded along each transect are provided in Appendix Figures A.3-1 to A.3-18 at Transects 1 to 20. The minimum, maximum, and mean dye concentration along each transect is summarized in Table B.1-12.

The mean transect concentrations in Table B.1-12 indicate that the downstream leading edge of the dye plume reached Transects 4, 7, and 12 respectively during the first 3 surveys. By survey 5 the dye arrived at Transect 17 (Key Bridge, 5.7 km downstream of Outfall 002), 9-hrs after the beginning of dye injection. Figure A.3-1 displays the dye build up at Transect 1 during the survey period. At this first transect, 520-m downstream of Outfall 002, the dye was already well mixed with a small concentration gradient increasing from left to right bank. Downstream at Transect 6 (Figure A.2-6) and Transect 10 (Figure A.2-8) the river widens out and the study results show a faster build-up of dye on the right bank (main channel) and the subsequent buildup of dye on the shallower left side of the river during later surveys. A more detailed discussion of the 24 May 2000 dye study results at Outfall 002 are provided in Appendix B.1.8.

Between surveys 3 and 4 during the 24 May 2000 dye study at Outfall 002, the survey boat was able to travel upstream of Transect 1 and perform several mapping transects in the vicinity of the discharge. The time interval between surveys 3 and 4 was near high water and the river currents upstream of Transect 1 were less than at other times during the study. The resulting dilution contour map is presented in Figure 2.1-5. During this survey (1322-1339-hrs) the discharge dye concentration was 34.2 ppb. Figure 2.1-5 indicates that the 10, 30, and 40 fold dilution contours were approximately 85-m, 135-m, and 190-m downstream of Outfall 002 along the discharge (left) bank. Downstream of the outfall, there was a very sharp lateral gradient as the dye mixed from the quieter back eddy formed in the lee of the shoreline protrusion at the discharge into the high velocity and turbulent flow coming from Little Falls. Within the 200-m region included in the dilution contour map, the plume gradually mixed across the remaining width of the river.

Turbidity Plume Mapping Surveys (25 May 2000)

On 25 May 2000, the suspended solids discharge event lasted for 3.5 hours, from approximately 0830 hours to 1200 hours. The effluent samples collected and analyzed for aluminum and TSS were previously presented in Table B.1-5. Four of the five effluent samples had TSS concentrations that varied between 4,600 mg/L and 16,500 mg/L.

The transects used during the turbidity survey were listed in Table 2.1-1 and illustrated in Figure 2.1-1. The times of the 4 turbidity mapping surveys are summarized in the following table.

25 May 2000 – Outfall 002

Survey	Time (hour)
Clean out	0830 – 1200
Survey 1	0907 – 1006
Survey 2	1101 – 1148
Survey 3	1259 – 1345
Survey 4	1445 – 1532

During all 4 surveys, transects were performed downstream to Transect 14. Although it was not possible to perform an upstream background transect, turbidity values at the downstream transects, ahead of the turbidity plume indicate background levels. The turbidity data recorded along each transect are provided in Appendix Figures A.4-1 to A.4-10 at Transects 1 to 14. The relationship between turbidity and TSS developed in Section 2.1.4 was used to create a second axis on these figures to display TSS. The minimum, maximum, and mean TSS concentrations along each transect are summarized in Table B.1-13.

Examination of Table B.1-13 indicates that TSS levels of 3-6 mg/L at Transects 12 and 14 during surveys 1 and 2 were most likely representative of background levels. During surveys 1 and 2, the highest TSS concentration along Transects 1 to 4 was 25.1 mg/L, and transect average concentrations varied between 11.4 and 18.5 mg/L. A more detailed description of the 25 May 2000 turbidity study results at Outfall 002 is provided in Appendix B.1.8.

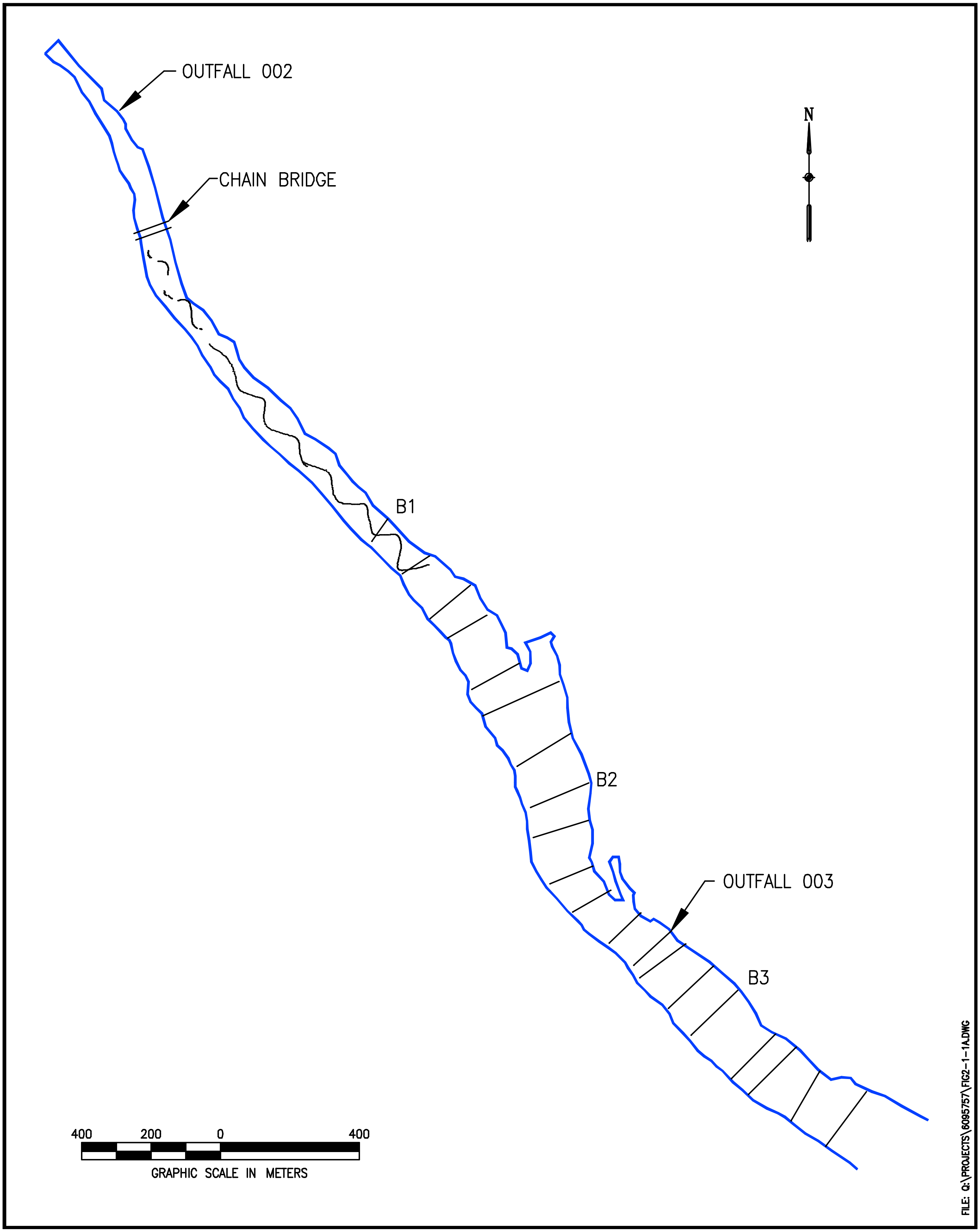


Figure 2.1-1A. Transects Used During the Bathymetry Study

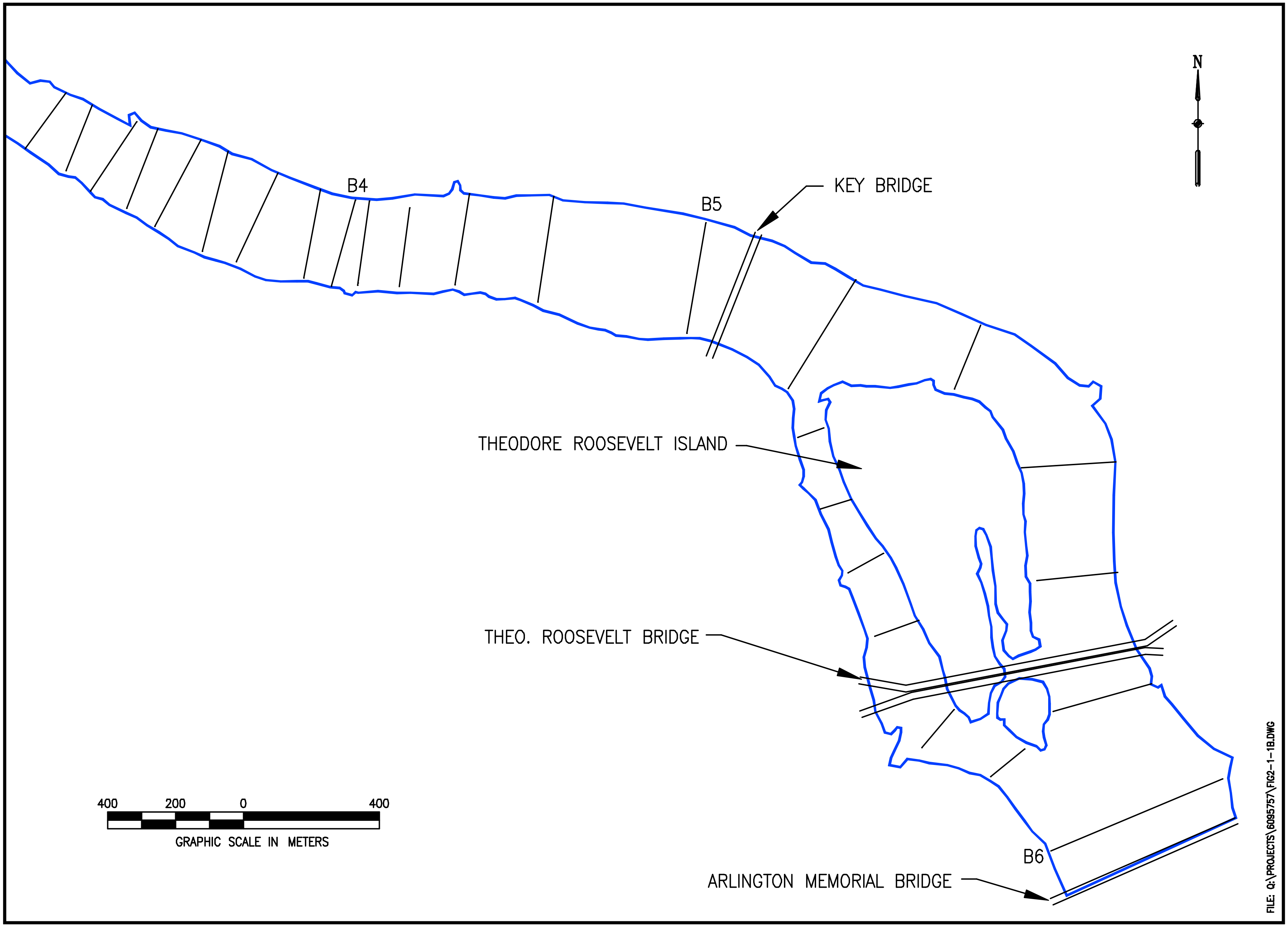
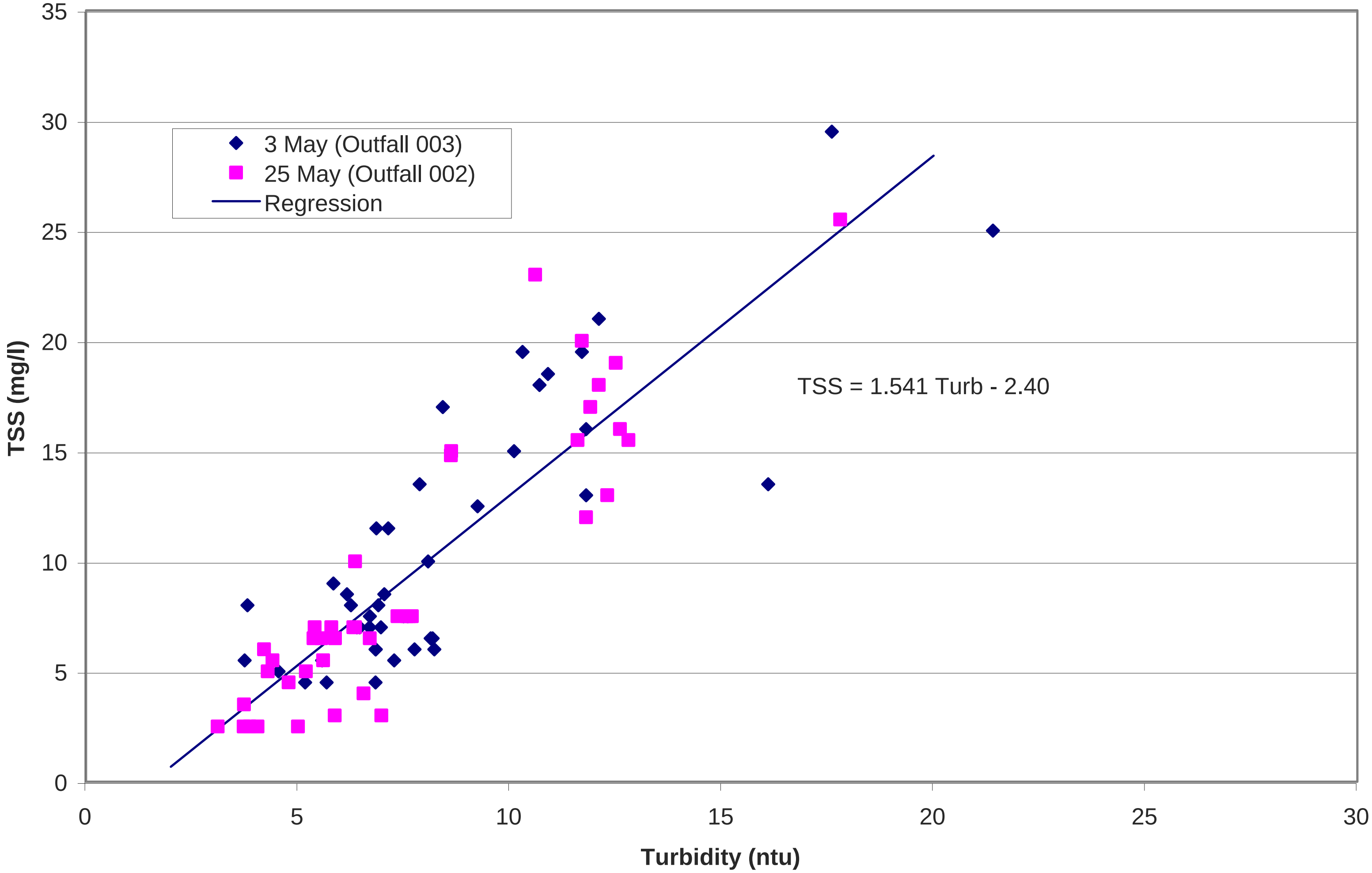


Figure B.1-1B. Transects Used During the Bathymetry Study

Figure 2.1-2 Relationship Between TSS and Turbidity in Water Samples Collected During the Turbidity Surveys at Outfalls 002 and 003



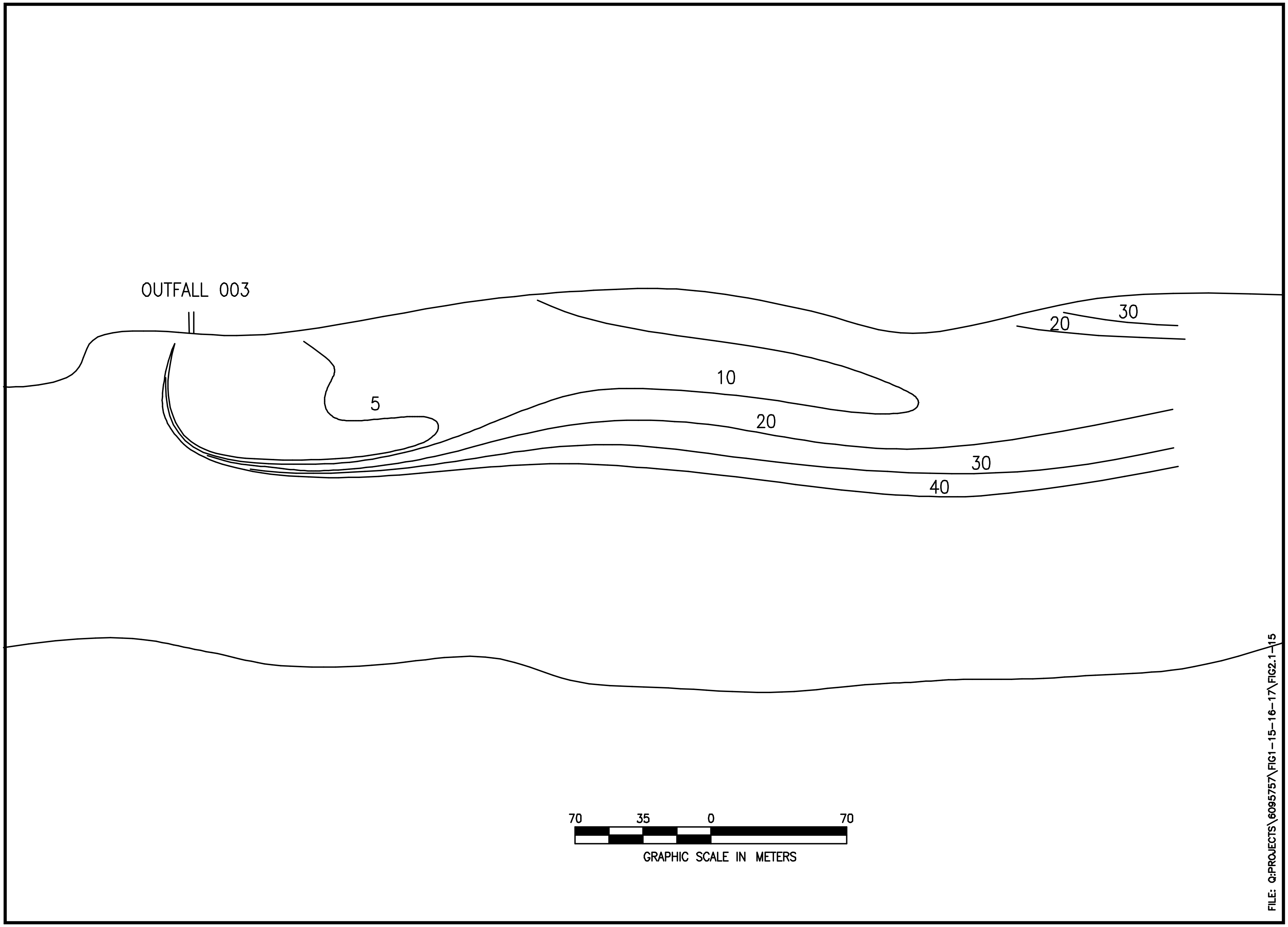


Figure 2.1-3. Average Dye Dilution Contours During Surveys 2 and 3 of the Outfall 003 Plume Mapping Survey, 2 May 2000

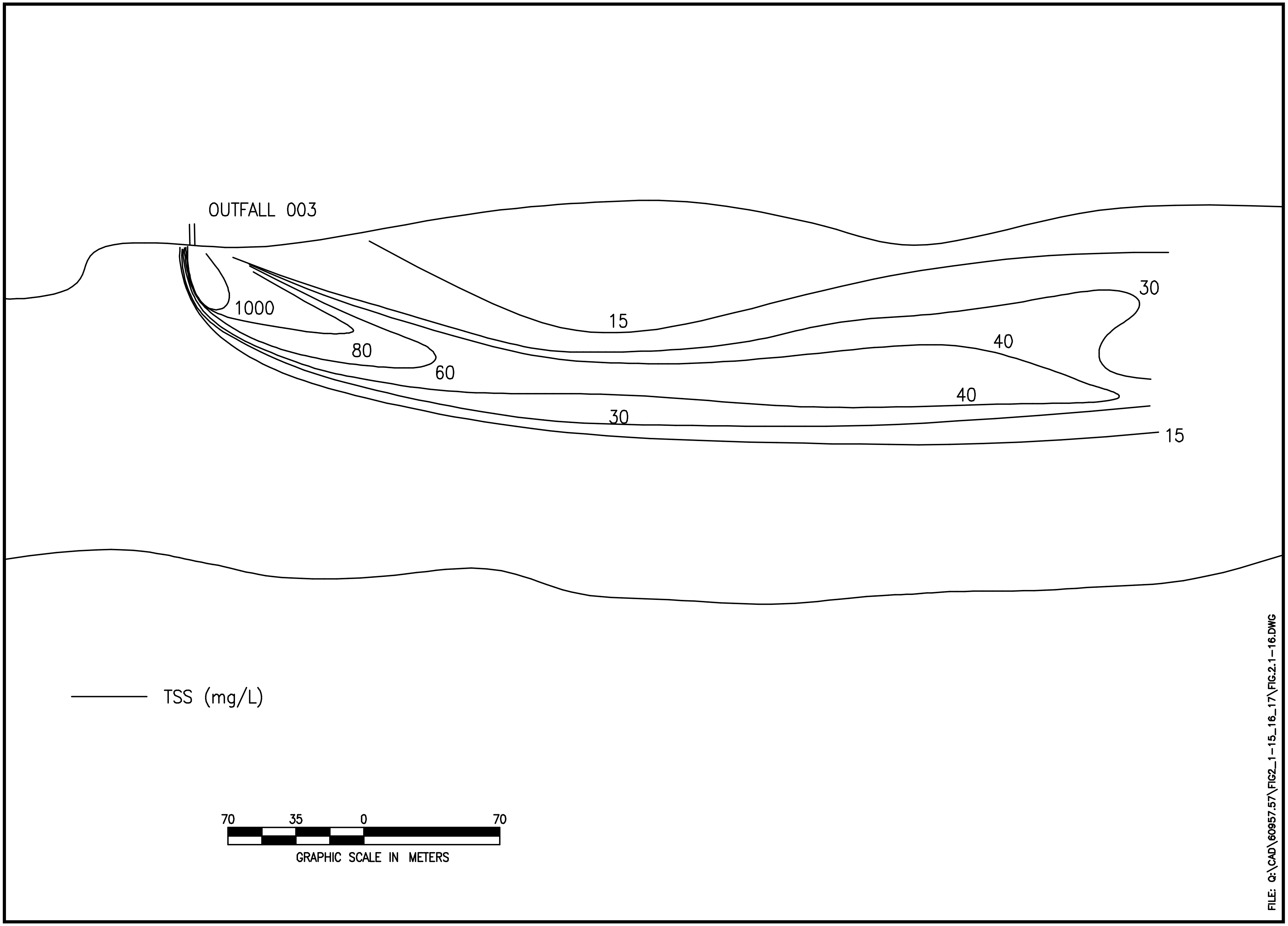


Figure 2.1-4. Maximum TSS Concentrations During the Turbidity Plume Mapping Surveys at Outfall 003, 3 May 2000

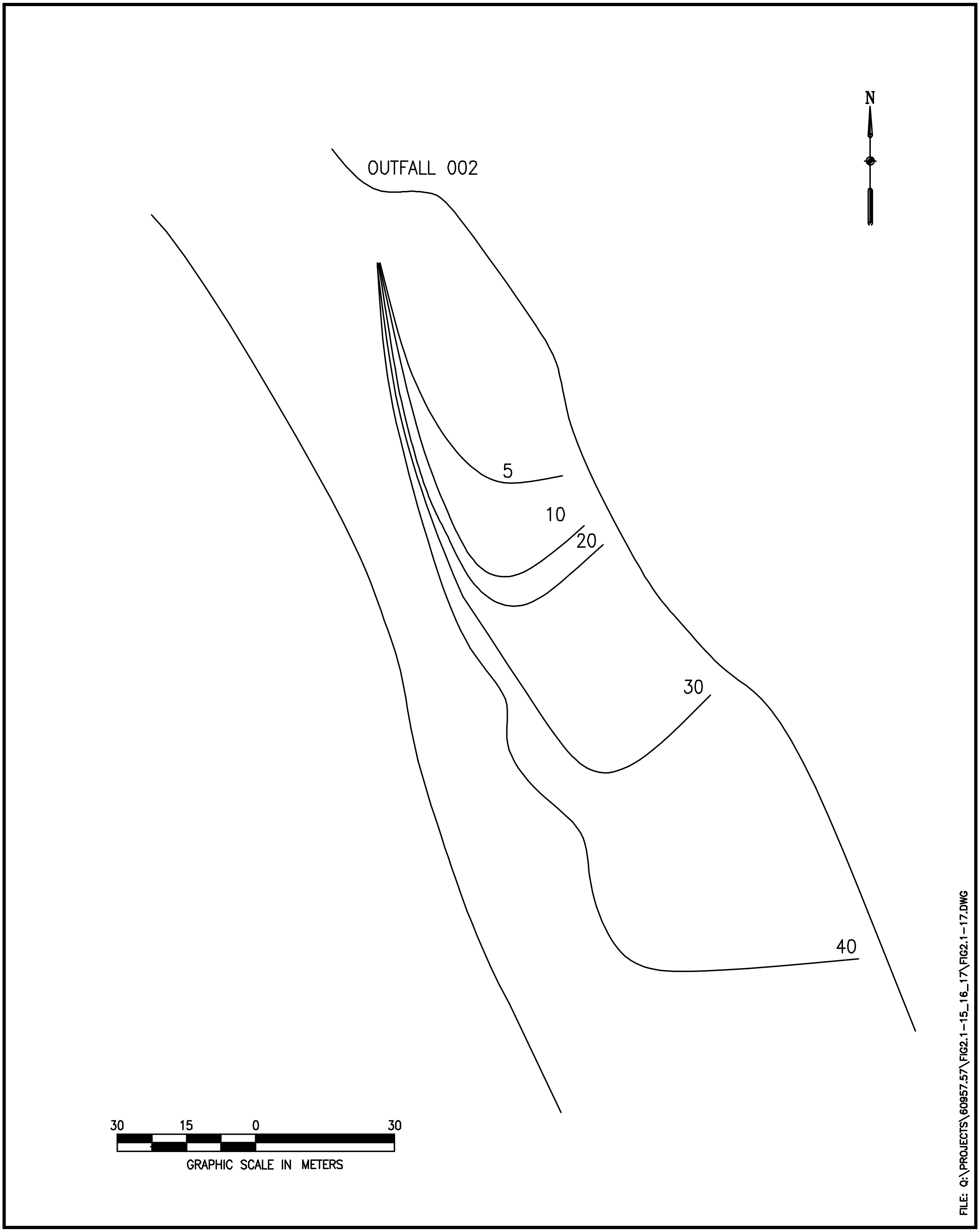


Figure 2.1–5. Dye Dillution Contours During the Outfall 002 Plume Mapping Survey, 24 May 2000(1320–1340 hrs.)

Table 2.1-1 Transects Used During the Dye and Turbidity Plume Mapping Surveys at Outfalls 002 and 003

Transect	Distance from 002 (m)	Distance from 003 (m)	Georgetown (003)		Dalecarlia (002)	
			Dye 2-May	Turbidity 3-May	Dye 24-May	Turbidity 25-May
1	520				x	x
2	790				x	x
3	1,150				x	x
4	1,560				x	x
5	1,880				x	x
6	2,280				x	x
7	2,780	-150	x	x	x	x
8	2,930	0	x	x		
9	3,000	70	x	x		
10	3,130	200	x	x	x	x
11	3,410	480	x	x	x	
12	3,830	900	x	x	x	x
13	4,320	1,390	x	x	x	
14	4,630	1,700	x	x	x	x
15	4,950	2,020	x	x	x	
16	5,190	2,260	x	x	x	
17	5,710	2,780	x	x	x	
18	6,640	3,710	x		x	
19	7,020	4,090	x		x	
20	7,980	5,050	x		x	

2.2 MODEL CALIBRATION

The model used to evaluate Aqueduct discharges to the Potomac River was the Surfacewater Modeling System (SMS), developed by BOSS International and Brigham Young University. SMS is a pre- and post-processor for surface water modeling and analysis. It includes interfaces with several numerical models including the U.S. Army Corps of Engineers, Waterways Experiment Station (WES) supported models RMA2, RMA4, and SED2D.

- RMA2 is a two-dimensional depth averaged finite-element hydrodynamic numerical model. It computes water surface elevations and horizontal components for free-surface flow in two-dimensional flow fields. RMA2 was used to provide a hydrodynamic solution for the modeled portion of the Potomac River. For the Aqueduct model, time-variable river flows were applied at the upstream model boundary, and time-variable tidal elevations were applied at the downstream model boundary. The resulting output file provides a flow velocity and a water surface elevation at each model node for each solution time step.

- RMA4 is a two-dimensional finite-element water quality model. The model simulates the advection-diffusion processes and treats pollutants either as conservative or nonconservative using first order decay. RMA4 uses the hydrodynamic solution file from RMA2 as an input file along with additional information on pollutant loadings and diffusion coefficients. As part of the Aqueduct model, RMA4 was used to simulate the discharge plumes resulting from the dye studies, while treating dye as a conservative tracer. The calibration of the Aqueduct model to the observed instream dye distribution was used to establish appropriate lateral and longitudinal diffusion coefficients.

- SED2D is a two-dimensional finite-element model for vertically averaged sediment transport in open channel flow. The model simulates both deposition and erosion and treats two sediment categories: 1) “noncohesive”, which is usually referred to as sand; and 2) “cohesive”, which is referred to as silt or clay. SED2D also uses the hydrodynamic solution file from RMA2 as an input file along with additional information including sediment loads, particle settling velocities, and shear stress for deposition and erosion. As part of the Aqueduct model, SED2D was used to model the suspended solids load during a reservoir clean-out event, and to simulate the resulting water column concentrations and the depositional patterns.

A more detailed discussion of the model calibration is provided in Appendix B.2.

2.2.1 Model Grid

The model domain was selected to extend from a location approximately 180-m upstream of Outfall 002, downstream past Roosevelt Island to Memorial Bridge. The total length of the model along the Potomac River was 8.0 km. The finite-element nature of RMA2 allows a variable model cell size to be used. Thus, a smaller element can be used in the vicinity of the outfalls where greater resolution is desired. The dynamic nature of the discharge flow entering transverse to the river flow and the accompanying large concentration gradients makes a smaller element size in the vicinity of the outfalls necessary for improved numerical stability. In the Aqueduct model, each of these far-field cells was typically 50-m long and 15 to 20-m wide. A much smaller element size was used in the vicinity of Outfalls 002 and 003. The model places nodes at the corner of each element and also mid-way along each side. The Aqueduct model contains a total of 2021 elements and 6281 nodes. For each model time step, the model solution files contains x and y velocity components, water surface elevations, and concentrations at each node. In general, the model was approximately 6 elements wide upstream in the vicinity of Outfall 002, increasing to 12 elements wide by Outfall 003. Between Outfall 003 and Roosevelt Island, the model maintained 12 elements across the river, although the element width varied with the river width resulting in curve-linear coordinates. A larger model element was used below Roosevelt Island approaching the downstream tidal boundary.

The finer model grid in the vicinity of Outfalls 002 and 003 are displayed in Figure 2.2-1. The smaller elements at Outfall 002 are approximately 5x5 m and the smaller elements at Outfall 003 are 5x7 m. The model grid used in the Potomac River beyond the vicinity of the outfalls is displayed in Figure 2.2-2, which extends from below Outfall 003 to the downstream end of the model at Arlington Memorial Bridge.

2.2.2 RMA2 Model Development

Model Boundaries

The RMA2 model was set-up using real-time data at the upstream and downstream boundaries. At the upstream boundary, the 15-minute USGS flow data was obtained at the Little Falls gage on days that field surveys were performed (Figures B.1-7 and B.1-10). At the downstream boundary the 5-min tide data obtained from the water level recorder deployed during each field survey was used.

Eddy Viscosity

The principal calibration parameters in RMA2 are eddy viscosity and channel roughness. Eddy viscosity (E) controls the fluid momentum transfer between water masses moving at different speeds. The eddy viscosity in the Aqueduct model was based upon a Peclet number. The Peclet number defines the relationship between velocity, elemental length, fluid density, and eddy viscosity. For a specified Peclet number, the eddy viscosity varies throughout the model in proportion to variation in velocity and element size. As the Peclet number is increased, the eddy viscosity decreases. A Peclet number of 20 was determined to provide numerical stability in the RMA2 model over a range of flow and tidal conditions.

Cross-Sectional River Velocity

The Manning's coefficient option was selected for determining channel roughness in the RMA2 model. The RMA2 model was executed for 6 and 7 April 2000 and the resulting velocities along Transects B3 and B4 were compared to observations. This comparison is illustrated in Figure B.2-3 for Transect B3 and Figure B.2-4 for Transect B4. The Manning's distribution selected for use in the model has the following form.

River Depth (m)	Manning's Coefficient
.5	0.047
2	0.035
4	0.030
6	0.027
10	0.024
14	0.023
16	0.021

2.2.3 Calibration of Diffusion to the Dye Survey Data (RMA4)

Longitudinal and lateral diffusion were calibrated by fitting RMA2/RMA4 to the dye plume mapping data obtained on 2 May 2000 at Outfall 003 (Georgetown Reservoir) and 24 May 2000 at Outfall 002 (Dalecarlia Basin).

On 2 May 2000 (Outfall 003, Georgetown Reservoir), the model was started at 0600 hour (near high slack) approximately 2.0 hours before Outfall 003 was turned on and the initiation of dye injection. The average discharge flow during the reservoir drawdown was 3.46 cms and discharge dye concentrations during the 6-hour dye release varied between 14.2 ppb and 21.2 ppb (Table B.1-8).

On 24 May 2000 (Outfall 002, Dalecarlia Basin), the model was started at 0600 hour (near low slack) approximately 2.0 hours before Outfall 002 was turned on and the initiation of dye injection. The average discharge flow during the reservoir drawdown was 1.73 cms and during the 6-hour dye release, discharge dye concentrations varied between 18.1 ppb and 34.2 ppb (Table B.1-10).

Diffusion coefficients were selected using a model option that automatically generates a value at every time step for each element based on the element size and average current velocity. The calculated diffusion value is scaled by a factor input by the user. A x-direction scale factor of 0.2 was used for the entire Aqueduct model. A value that was within the recommended range. The y-direction diffusion coefficient is set as a fraction of the x-direction diffusion coefficient. In order to fit the RMA4 model to the dye plume mapping data during the calibration process it was necessary for the y-direction diffusion scale factor to vary between several regions.

Beyond the vicinity of Outfalls 002 and 003, a y-direction scale factor of 0.15 was used throughout the model (region 1). Downstream of Outfall 002 the y-direction scale factor was increased to 0.7 for a 420-m reach in order to obtain the lateral nearly mixed condition observed at Transect 1 (region 2). The y-direction scale factor was increased in two regions associated with Outfall 003. The first being a 40x40-m region directly in front of Outfall 003 (region 3), and the second region extended 620-m downstream and approximately 80-m offshore along the shallow near shore zone (region 4). The two regions associated with Outfall 003 were not needed during the Outfall 002 simulations. The model parameters used in the resulting four regions of the model are summarized in the following table.

Region	**Peclet**	**x-Dir Scaling**	**y-Direction Scaling**	
			002 Simulation	**003 Simulation**
1) Main Model	20	0.20	0.15	0.15
2) Downstream 002	20	0.20	0.70	0.70
3) Adjacent 003	20	0.20	0.15	0.40
4) Downstream 003	20	0.20	0.15	0.25

A comparison of predicted and observed dye concentrations at the survey transects for the 2 May 2000 Outfall 003 study (Georgetown Reservoir) are provided in Figures B.2-5 and B.2-6. A comparison of predicted and observed dye concentrations for the 24 May 2000 Outfall 002 study (Dalecarlia Basin) are provided in Figures B.2-7 to B.2-9. A discussion of the goodness-of-fit of the predicted and observed dye concentrations at the transects represented in these figures is provided in Appendix B.2.3. In general, the agreement between t model predictions and observations were considered to be very good.

2.2.4 Modeling the Suspended Solids Plume (SED2D)

The suspended solids discharge from the Georgetown Reservoir (Outfall 003, 3 May 2000) and Dalecarlia Basin (Outfall 002, 25 May2000) were modeled with SED2D. SED2D requires the RMA2 hydrodynamic output file, diffusion coefficients, and the particle characteristics of the material being discharged. Diffusion in SED2D was parameterized to match the values selected in RMA4 based on the dye study surveys.

Particle Characteristics

The composite particle size distribution based on sediment samples collected during this project from the Georgetown and Dalecarlia Reservoirs indicated that the material was 65.7 % sand, 22.0 % silt, and 12.3 % clay (Table B.1-6). However, this particle distribution does not reflect the presence of the floc resulting from the addition of alum in the water treatment process. An analysis of particle size without using a de-floccing agent (which is typically used in particle size determinations) yielded a much narrower range of particle size with an absence of the finer clays (Table B.1-7).

Modeling the discharged material as a single particle classification (floc) was not considered to be realistic because considerations of all the available data indicated that a coarser and finer material were also likely to be present. Based upon a discussion in Appendix B.2.4, three particle classifications were selected for simulation with SED2D: sand 25%, floc 65%, and silt 10 %.

The particle size distribution from the ASTM settling tests and the particle scenario selected for the model are compared in the following table.

ASTM Test Results				Model Scenario		
Material	**Dia (mm)**	**ASTM (%)**	**Floc (%)**	**Material**	**Dia (mm)**	**Percent**
Sand	> 0.05	65.7	88.2	Sand	> 0.05	25
Silt	0.002-0.05	22.0	11.8	Floc	> 0.05	65
Clay	< 0.002	12.3	0	Silt	< 0.05	10

SED2D provides different mechanisms for the simulation of noncohesive particles (sand) and cohesive particles (silt and clay). The floc was modeled using the cohesive particle mechanism. For sand, the model requires the particle diameter, settling velocity, and material density. For a cohesive particle, the model requires settling velocity and shear stresses for deposition and erosion. SED2D calculates a bottom shear stress as a function of velocity and channel friction at each location in the model. The bottom shear stress must be below the depositional shear stress for a particle to be deposited. If the bottom shear stress increases above the erosional shear stress, a particle will be resuspended.

The relationship between particle size, shear stress, and other physical site conditions effecting sediment transport is under active investigation by the U.S. Army Engineer Waterways Experiment Station (WES) and other investigators. Based upon a review of the particle data and sediment characteristics (see Appendix B.2.4), the following particle attributes were used in the model.

Particle Characteristics

Parameter	**Sand**		**Parameter**	**Floc**	**Silt**
Diameter (mm)	0.05		Diameter (mm)	.05	.002
Settling Vel.(m/sec)	0.00208		Settling Vel. (m/sec)	2.4E-4	8.2E-5
Density (gm/cm^3)	2.5		Shear Stress (newton/m^2)	0.1	0.1

SED2D Model Execution

SED2D was executed three time for each of the two outfalls to provide model simulations for the sand, floc, and silt particle classes. The water column TSS concentrations for the three particle classes were summed at each model node to provide composite TSS concentrations. In general, the TSS discharge concentration was modeled as being 10,000 mg/L using a 0.132-cms flow at Dalecarlia Basin and a 1.138-cms flow at Georgetown Reservoir. A 3.5-hour suspended solids discharge event was modeled at both outfalls.

A summary of the total mass included in the discharge scenario at each outfall is provided in the following table.

Mass of Discharged Solids (kg)

Material	Outfall 002 (Dalecarlia)	Outfall 003 (Georgetown)
Sand	4,455	38,407
Floc	11,583	99,860
Silt	1,782	15,363
Total	17,820	153,630

The surface area of Georgetown Reservoir (66,425 m^2) is approximately 11 times greater than the surface area of Dalecarlia Basin 3 (5,897 m^2). The increase in mass of solids discharged at Outfall 003 is approximately proportional to the increase in reservoir size.

A frequency distribution of suspended load at Chain Bridge, based on historical USGS data, is presented in Chapter 4 (Section 4.3.2, Table 4-5). The 17,820-kg discharged solids mass at Outfall 002 is less than a lower 10-percentile value of the daily Potomac River suspended load. The 153,630-kg discharged solids mass at Outfall 003 is between a 40- and 45-percentile of daily Potomac River suspended load.

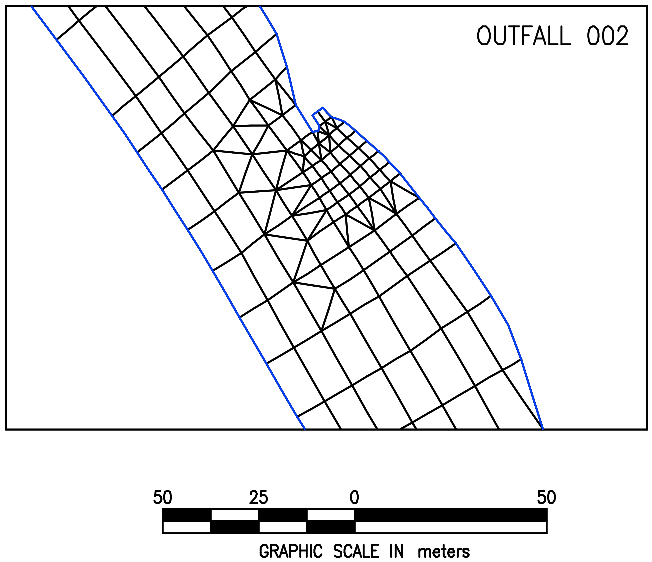
A comparison between observed surface and predicted TSS values is provided in Figures B.2-12 and B.2-13 for Outfall 002 from Dalecarlia Basin, and in Figures B.2-14 and B.2-15 for Outfall 003 from Georgetown Reservoir. The SED2D model output only contained the TSS loadings from the outfalls and did not include the natural background concentrations in the Potomac River. This was done to allow the model to illustrate the incremental increase in TSS concentration directly associated with operations at the reservoirs. However, to make comparisons to the observed survey data, a background TSS concentration was added to the model predictions when generating the figures. The background concentrations were selected based upon examination of the survey data. For the 3 May 2000 survey at Outfall 003, a background TSS concentration of 8 mg/L was used at Transects 10 to 14, decreasing to 6 mg/L at Transect 16. For the 25 May 2000 survey at Outfall 002, a background TSS concentration of 8 mg/L was used at Transects 1 to 8, decreasing to 6 mg/L at Transect 10, and 3 mg/L at Transect 12.

Figure B.2-12 for Dalecarlia Basin displays good agreement between predicted and observed TSS concentrations downstream from Outfall 002 at Transects 1 and 4 during surveys 2, 3, and

4. Surveys 3 and 4 were performed after the solids clean-out event had ended and TSS concentration were decreasing to background levels.

Figure B.2-14 for Georgetown Reservoir provides results at Transect 11 (480-m downstream from Outfall 003) and Transect 12 (900-m downstream). At Transect 11, the decrease in TSS concentrations near the left bank and the sharp delineation of the plume width at approximately one-half the river width were well represented by the model. The lower near-shore concentrations and a higher off-shore plume centerline were features associated with the back-eddy formed downstream of the outfall. The lower observed concentrations during survey 3, the time of maximum plume build-up, were attributed to water column stratification. Before coming well mixed, the higher density suspended solids plume is concentrated in the lower portion of the water column, resulting in higher water column average TSS concentrations than would be observed with a near surface probe.

A more detailed discussion of the comparison of the observed and predicted TSS values at Outfalls 002 and 003 is provided in Appendix B.2.4.



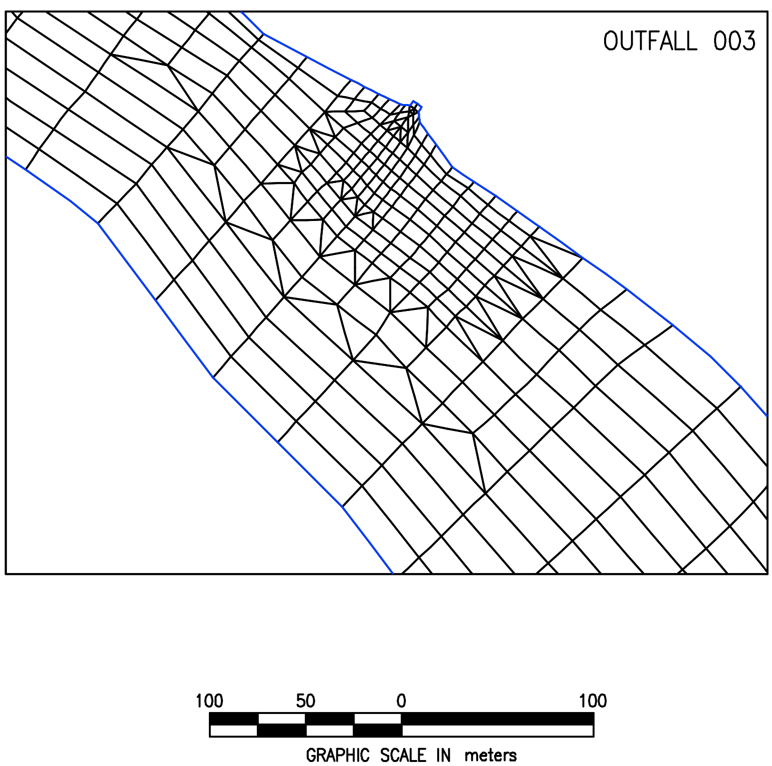


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Figure 2.2-1. Near-Field Model Grid Used at Outfalls 002 and 003

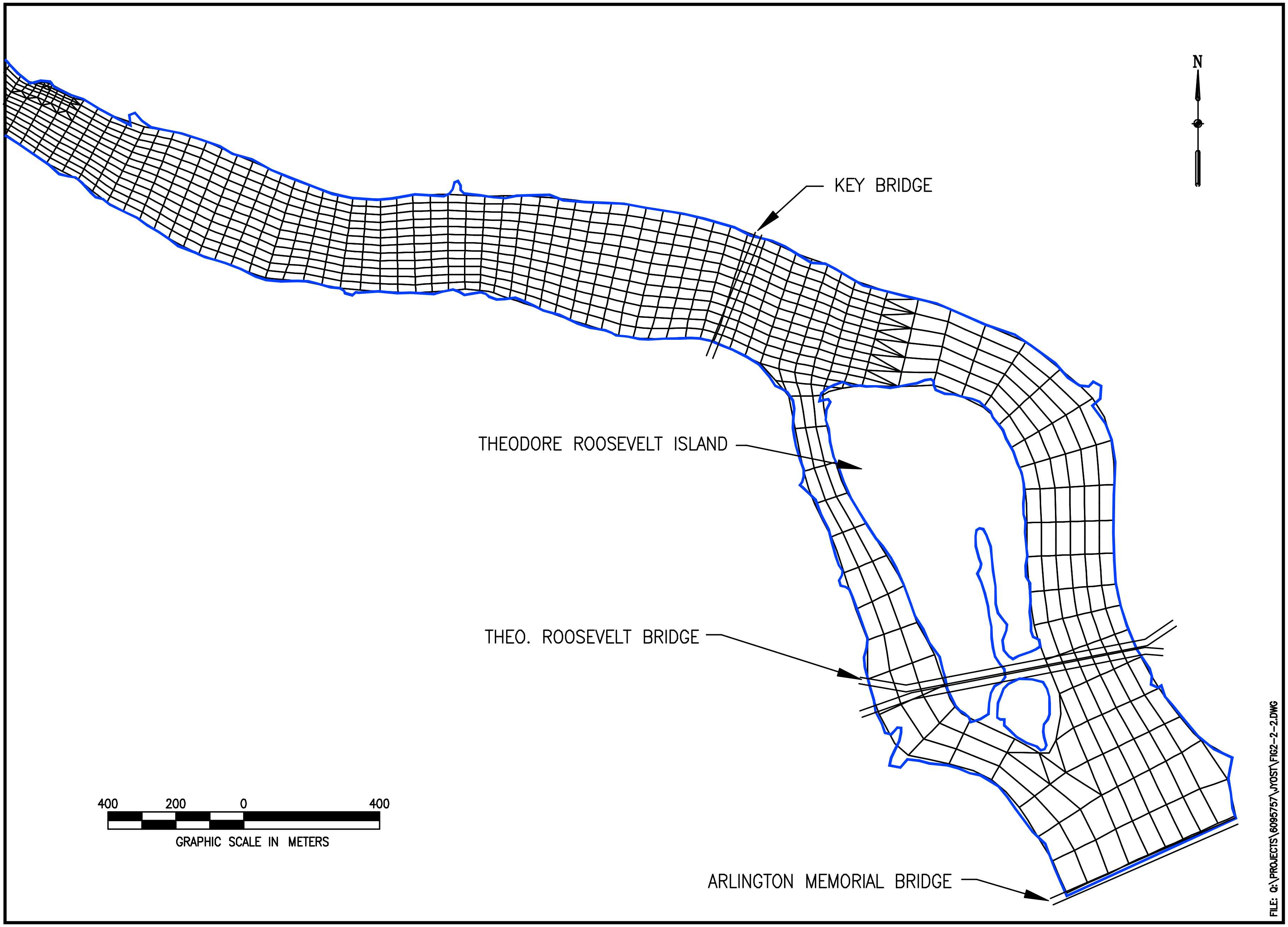


Figure 2.2–2. Model Grid Used in the Downstream Portion of the Potomac River Model

2.3 SUSPENDED SOLIDS FATE AND MIXING ZONE DILUTION FACTORS

The SMS model was used to examine the fate of the solids during the Outfall 002 and Outfall 003 discharge events and to determine mixing zone dimensions associated with a range of dilution factors at each outfall. The model runs performed during calibration typically extended 6 hours beyond the end of the solids discharge event. At the end of these runs, suspended solids were still present in the water column and the plume had not progressed beyond the downstream end of the model. The solids discharge events at Outfalls 002 and 003 were re-executed using a 24-hour model run. This a1lowed the suspended solids mass in the water column resulting from the discharge event to approach zero as a result of deposition and the remnant plume passing beyond the downstream end of the model.

2.3.1 Suspended Solids Fate at Outfall 002

The total TSS concentrations in the water column were determined by summing the results for the sand, floc, and silt from the 24-hour model runs at each model node and time step. The resulting time history of the individual components and of the total suspended solids was used to examine the fate of the discharged material in the Potomac River. The text and figures in the following sections do not include the natural background Potomac River TSS concentrations, but only display the incremental increase associated with the discharges. The background TSS concentrations were typically 6-8 mg/L, and under wet weather conditions, TSS concentrations commonly range up to 100 mg/L.

The distribution of suspended and deposited solids during a 24-hour model run at Outfall 002 is summarized in Figure 2.3-1 and Table 2.3-1. The time scale in the figure and table starts at the beginning of the clean-out event. The discharge event occurred between 0.0 and 3.5 hours. The fraction of suspended solids associated with sand reached zero at 7.5-hours, 4-hours after the end of the discharge event, and the suspended fraction associated with floc and silt approached zero by 21.5-hours, 18-hours after the end of the discharge event. The decrease in the curve representing the total solids mass in the system (both suspended and deposited) between approximately 12 and 20 hours represents the remnant suspended plume passing beyond the downstream end of the model. Based on the model, approximately 4,400 kg (22 percent) of the total mass discharged from Outfall 002 passed beyond the downstream end of the model in 24 hours.

The modeled TSS plumes in the Potomac River are provided in Figures 2.3-2, 2.3-3, and 2.3-4 at times corresponding to the end of the solids discharge event, and 2 hours, and 4 hours following the event. The comparison of observed and predicted results in Section 2.2.4 indicated that the TSS plume very quickly becomes fully mixed.

- At the end of the discharge event (Figure 2.3-2), the leading edge of the plume (the 2-mg/L TSS contour) had reached a location approximately 3,400-m downstream of Outfall 002 and the 10 mg/L TSS was confined to within 350-m of the outfall.

- As shown in Figure 2.3-3, the TSS plume 2-hours following the end of the solids discharge event, as defined by the 1-mg/L contour, had a total length of 2,600 m, centered at a location 3,400 m downstream of Outfall 002 (centered approximately at the location of Outfall 003). After 2-hours, the discharged suspended solids had been flushed out of the 2,000-m reach downstream of Outfall 002 and the maximum TSS concentrations in the remaining plume were less than 6 mg/L.

- The TSS plume 4-hours following the end of the solids discharge event had a length of approximately 2,300-m between the leading and trailing 1-mg/L contours (Figure 2.3-4). The center of mass of the remnant plume was approximately 4,600 m downstream of Outfall 002 and the maximum suspended TSS concentration was less than 5 mg/L.

The maximum extent of the depositional footprint resulting from the discharge event is represented by conditions at the end of the 24-hour model run, when the suspended solids concentrations approach zero. The resulting mass of sand, floc, and silt deposited to the bed at each model node was converted to a thickness. The bed thickness associated with a deposited mass is dependent on the depositional density of the material. The SMS model assumes that sand has a porosity of 0.4, resulting in a density of 1,500 gm/L. The depositional density of floc and silt is much lower due to a high water content and an expected range is 200-500 gm/L. A density of 200 gm/L corresponds to a porosity of 0.92. The bed thickness associated with sand and two densities associated with floc and silt are provided in the following table for a range mass deposition.

Bed Thickness (mm)

Deposition (gm/m^2)	Sand 1,500 gm/L	Floc and Silt 200 gm/L	Floc and Silt 500 gm/L
5	0.0033	0.025	0.010
10	0.0067	0.05	0.020
20	0.013	0.10	0.040
50	0.033	0.25	0.10
100	0.067	0.50	0.20
500	0.33	1.0	0.40

To be conservative, the total deposited thickness at each model node was calculated assuming that the depositional density was 1,500 mg/L for sand, and 200 gm/L for floc and silt.

The depositional footprint from a solids discharge event at Outfall 002 is provided in Figure 2.3-5 (a, b). A figure is presented for two river reaches to provide coverage of the entire model domain. Figure 2.3-5a displays deposition in the higher velocity, more confined Potomac River reach downstream of Outfall 002. At Outfall 002, there is a depositional zone extending approximately 400 m along the lower velocity discharge bank. Just below the outfall, deposition exceeds 0.1 mm, while the remainder of the 400-m region typically exceeded 0.01 mm. At the slight bend in the vicinity of Transect 1, there was a 250-m reach with very low deposition (< 0.01 mm). Immediately downstream of this low deposition region, deposition increased to greater than 0.02 mm, and tapered off to 0.01 mm approximately 2,000 m downstream of the outfall. The higher deposition that occurred downstream of the bend at Transect 1 was associated with sand, resulting from the channel velocity decreasing due to both a widening and deepening of the channel compared to the more confined channel adjacent to the outfall.

Figure 2.3-5b displays the depositional pattern in the downstream half of the model domain. Upstream of Roosevelt Island, deposition was typically 0.03 mm. In the vicinity of Roosevelt Island, deposition exceeded 0.02 mm in the main channel on the east side of the island, and was less than 0.01 mm in the smaller channel on the west side of the island.

2.3.2 Suspended Solids Fate at Outfall 003

The total TSS concentrations in the water column at Outfall 003 were determined by summing the results for the sand, floc, and silt from the 24-hour model runs at each model node and time step. The resulting time history of the individual components and of the total suspended solids was used to examine the fate of the discharged material. The text and figures in the following sections do not include the natural background Potomac River TSS concentrations, but only display the incremental increase associated with the discharges.

The distribution of suspended and deposited solids during a 24-hour model run at Outfall 003 is summarized in Figure 2.3-6 and Table 2.3-2. The fraction of suspended solids associated with sand reached zero at 6.5-hours, 3-hours after the end of the discharge event, and the suspended fraction associated with floc and silt neared zero by 22-hours, 18.5-hours after the end of the discharge event.   The decrease in the curve representing the total solids mass in the system (both suspended and deposited) between approximately 9 and 20 hours represents the remnant suspended plume passing beyond the downstream end of the model. Approximately 20,000 kg (13 percent) of the total mass discharged passed beyond the downstream end of the model.

The modeled TSS plumes in the Potomac River are provided in Figures 2.3-7, 2.3-8, and 2.3-9 at times corresponding to the end of the solids discharge event, and 2 hours, and 4 hours following the event.

- At the end of the discharge event (Figure 2.3-7), the 5-mg/L TSS contour had reached a location approximately 2,000 m downstream of Outfall 003 and the 100-mg/L TSS contour was confined to within 350 m of the outfall. The higher TSS contours extended along the discharge bank (left bank) and a 5-mg/L contour was in the vicinity of the main channel towards the right bank.

- Two-hours following the end of the solids discharge event (Figure 2.3-8), the 2-mg/L TSS contour extended approximately 3,700 m downstream, reaching the vicinity of Roosevelt Island. TSS concentrations in the vicinity of Outfall 003, which exceeded 1,000 mg/L during the discharge event had decreased to less than 100 mg/L. The 20-mg/L contour, which extended 1,000 m at the end of the discharge event (Figure 2.3-7), now reached a downstream distance of approximately 1,500 m, although it was confined to the narrower near-shore zone.

- At 4-hours following the end of the solids discharge event (Figure 2.3-9) the 2-mg/L contour had moved only about 600-m downstream from it's 2-hr location. This relatively small downstream movement resulted from low Potomac River velocities near high tide and the beginning of flood. A remnant suspended TSS plume of less than 10 mg/L still existed along the shallow near-shore region downstream of Outfall 003. However, TSS concentrations along the main channel on the right half of the river had been flushed out for a 1,500-m distance downstream of the outfall.

Model results at the 22-hour time step with a near zero suspended solids concentration, represents the maximum extent of the depositional footprint resulting from the discharge event at Outfall 003. The resulting deposited mass at each model node for the three material classes were converted to thickness assuming a depositional density of 1,500 mg/L for sand and 200 gm/L for floc and silt, as discussed in the previous section.

The resulting depositional footprint from a solids discharge event at Outfall 003 is provided in Figure 2.3-10. The depositional zone immediately in front of Outfall 003 exceeded 20 mm and the 5-mm contour extended approximately 200-m downstream, and a 1-mm contour extended approximately 350-m downstream. The 0.2-mm depositional contour extended 2,500-m downstream along the left bank. There was minimal deposition within the main channel for the first 800-m downstream from Outfall 003. Between 800-m and 2,000-m downstream, deposition of 0.05-0.10 mm was present near the right bank, and deposition along the main channel typically did not exceed 0.01 mm. In the vicinity of Roosevelt Island, deposition of typically 0.05 mm was present in the main channel along the east side of the island, and deposition of 0.01-0.02 mm was present in the smaller channel on the west side of the island.

2.3.3 Mixing Zones

Section 1105.7 of the D.C. DOH's regulations allow for mixing zones where it is demonstrated that a small area of impact "will not adversely affect the waterbody as a whole." Within the estuary, paragraph (f) of the District's regulations states that "the maximum cross sectional area occupied by a mixing zone for chronic water quality criteria shall not exceed ten percent (10%) of the numerical value of the cross-sectional area of the waterway, and the width of the mixing zone shall not occupy more than one third (1/3) of the width of the waterway. Paragraph (i) states that the mixing zone shall be sized by using the EPA guidance (EPA's TSD) and approved by the Director.

Section 4.4.4 of EPA's TSD provides several alternative approaches for determining the size of an acute mixing zone with the goal of "preventing lethality or other acute effects" (p.71). "Lethality [and other acute effects] is a function of the magnitude of pollutant concentrations and the duration an organism is exposed to those concentrations." As an alternative, the Agency states that the mixing zone can be sized such that a drifting organism would not be exposed to 1-hour average concentrations exceeding the acute criterion, or would not receive harmful exposure when evaluated by other valid toxicological analysis, and discussed in TSD Section 2.2.2" (p. 72). This approach is often termed the one-hour float time.

The Aqueduct model was executed for three river flow scenarios to determine mixing zone characteristics (width, cross-sectional area) and the 1-hour float time associated with both Outfalls 002 and 003. Washington Aqueduct's existing permit limits solid discharge events to times when river flows are above a 3.47-ft gage height, which corresponds to 153 cms (5,400 cfs). In addition to the 153-cms river flow scenario, a river flow of 100 cms and 250 cms was selected to illustrate a range of river conditions. Potomac River flows greater than 153 cms occur less than 30 percent of the time during July, and less than 20 percent of the time during August to October. The Aqueduct must therefore clean all of it's reservoirs and basins during the spring in order to last until the next opportunity in the late fall. The 100-cms river flow condition was performed to illustrate the possibility of discharging during lower summer flows, and thus avoiding more critical biological conditions in the spring. For each river flow scenario, the model was executed using a mean tide range and outfall flows corresponding to the flow used during the 3 May 2000 and 24 May 2000 discharge events (0.132 cms at Outfall 002 and 1.138 cms at Outfall 003). The model was executed using a conservative dye tracer in order to provide dilution contours.

Plume dimensions associated with various dilution contours were summarized during a mid-ebb tide and during a mid-flood tide. Since a Potomac River flow reversal does not take place within the modeled flow range, a slack tide condition does not occur. The resulting range of river velocities is bracketed by the mid-ebb and mid-flood condition. The downstream distance to each dilution contour was determined by measuring dimensions on graphical output generated by SMS. At each outfall, a cross-section was selected just downstream of the discharge that exhibited maximum width. A computer program processed the predicted dye concentrations along this cross-section to develop a table of plume widths and cross-sectional areas. The cross-sectional analysis program accounts for lower near-shore concentrations when the plume centerline is not shore attached. The dilution associated with a 1-hr average float time was also determined. A computer program was used that searched along each set of lateral nodes in the model grid downstream of the discharge to identify the location of the maximum concentration (minimum dilution). The concentration exposure history of a particle was calculated along this maximum centerline concentration using the velocity field associated with the node of maximum concentration. The results of this dilution analysis are provided in Tables 2.3-3 and 2.3-4 for Outfall 002 and in Table 2.3-5 and 2.3-6 for Outfall 003.

Outfall 002

Table 2.3-3 provides dilution factors for Outfall 002 (0.132 cms) under three river flow scenarios during an ebb and flood tide. Dilution contours at Outfall 002 for an ebb tide scenario are illustrated in Figure 2.3-11 at a 153-cms river flow. The 0.132-cms flow at Outfall 002 has a maximum dilution factor of 1,160 when fully mixed into a 153-cms river flow. At a 153-cms river flow, the available dilution factor increased from 50 to 100 as the downstream distance increased from 29.1 m to 54.2 m. At a lower river flow of 100 cms, the distance necessary for a dilution factor of 50 increased from 29.1 to 36.1 m, while at a higher river flow of 250 cms, the distance decreased to 10.7 m. During a flood tide, dilution contours occurred at approximately a 10 percent shorter distance for all three river flow scenarios.

The dilution contours in Figure 2.3-11 can be compared to the dye plume map that was generated during the 24 May 2000 dye study (Figure 2.1-5). In Figure 2.1-5, the factor of 40 dilution contour extended approximately 180-m downstream, considerably farther than the 54-m distance for the 100-dilution contour in Figure 2.3-11. It must be remembered that during the dye study (which occurred during the basin decant process), the discharge flow was 1.73 cms, while during the reservoir clean-out, the discharge flow was only 0.132 cms. With some approximation, the two scenarios can be scaled by the 13.1 ratio between their discharge flows. This would indicate that the 100-dilution contour at the solids discharge flow (0.132 cms) is similar to the 7.6-dilution contour during the dye study (1.73 cms). With this consideration, the two dilution contour figures are in reasonable agreement.

The dilution factor associated with a 1-hr average exposure time (acute mixing zone) was 169 at a 153-cms river flow. The 1-hr average dilution factor decreased to 109 for a 100-cms river flow and increased to 282 for a 250-cms river flow. During a flood tide, the 1-hr average dilution was reduced slightly with a value of 156 for the 153-cms river flow scenario (Table 2.3-3).

Table 2.3-4 provides plume widths and cross-sectional areas at Outfall 002 during an ebb tide for three river flows, and for a range of dilution factors. The cross-sectional analysis was performed at transects 3-m and 7-m downstream of the outfall. At the 153-cms and 250-cms river flows, the 3-m transect had larger plume widths and these results were used in the table. At the lower 100-cms river flow, the 3-m transect had larger plume widths at dilution factors below 30 and the 7-m transect had larger plume widths above a dilution factor of 30.

With respect to the D.C.DOH criteria for plume width (33.3 percent) and cross-sectional area (10 percent), a chronic mixing zone at Outfall 002 is limited by it’s cross-sectional area. At a river flow of 153-cms, 10 percent of the cross-sectional area is associated with a dilution factor of approximately 51, and is equivalent to 18.6 percent of the river width. At a river flow of 250-cms, 10 percent of the cross-sectional area increases to a dilution factor greater than 80, while at a lower 100-cms river flow, the 10-percent criteria is met by a dilution factor of 33.

Outfall 003

Table 2.3-5 provides dilution factors for Outfall 003 under three river flow scenarios during an ebb and flood tide. Dilution contours at Outfall 003 for an ebb tide scenario are illustrated in Figure 2.3-12 at a 153-cms river flow. The 1.138-cms flow at Outfall 003 has a maximum dilution factor of 136 when fully mixed into a 153-cms river flow (Table 2.3-5). During an ebb tide and at a 153-cms river flow, the downstream plume length was 302 m for a dilution contour of 20 and 488 m for a dilution factor of 40. At a 100-cms river flow, downstream distances were slightly shorter, 293 m to a dilution contour of 20. At a higher 250-cms river flow, downstream distances were slightly shorter at dilution factors less 30, reflecting greater initial dilution in the higher river flow. At larger dilution factors of 40 to 50, the downstream distance increased due to the more rapid plume transport at the higher river velocities. During a flood tide, downstream distances were slightly shorter. For example, at a 153-cms river flow the distance for a dilution factor of 20 decreased from 302 m during ebb tide to 284 m during flood tide.

The dilution contours in Figure 2.3-12 (1.138 cms) can be compared to Figure 2.1-3 generated during the 2 May 2000 dye plume mapping study (3.46 cms). The river flow during the 2 May 2000 dye study was 300-cms, slightly larger than the 250-cms model scenario. The two figures exhibit similar plume widths, indicating that plume width is more dependent on the width of the shallow near-shore zone than to discharge flow. In Figure 2.1-3, the downstream distances to the 10-dilution contour was 380 m, respectively, while in Table 2.3-5 for a 250-cms river flow, the 10-dilution contour was at a distance of 176 m. The shorter plume length predicted by the model is consistent with how one would expect the plume to respond when the discharge flow was reduced from the higher 3.46-cms value present during the reservoir decant process to the lower 1.138-ms flow associated with the reservoir clean-out.

The dilution factor for an acute mixing zone associated with a 1-hr average exposure time was 2.33 during an ebb tide and 2.31 during a flood tide at a 153-cms river flow. The 1-hr average dilution for the ebb tide scenario decreased to 2.16 for the lower 100-cms river flow, and increased to 2.65 for a 250-cms river flow. For the flood tide scenarios, the 1-hr average dilutions were nearly identical to the ebb tide results.

Plume widths and cross-sectional areas at Outfall 003 are provided in Table 2.3-6 during an ebb tide for three river flows, and for a range of dilution factors. The dilution contours illustrated in Figure 2.3-12 indicate a sharp lateral gradient in plume width at approximately 40 percent of the river width, the boundary between the shallower near-shore region and the deeper channel. At a transect 90-m downstream of Outfall 003 and for a 153-cms river flow scenario, plume widths increased from 22.4 percent to 43.7 percent of the river as the dilution factor increased from 5 to 50. The corresponding plume cross-sectional areas increased from 12.4 percent for a dilution of 5, to 20.6 percent for a dilution of 50.

With respect to the D.C.DOH criteria for plume width (33.3 percent) and cross-sectional area (10 percent), a chronic mixing zone at Outfall 003 is limited by it's cross-sectional area. At a river flow of 153-cms, 10 percent of the cross-sectional area is associated with a dilution factor of 4.3, while the 33.3 percent width criteria corresponds to a larger dilution factor of 8.1. At a 100-cms river flow, the dilution factor for a 10-percent cross-sectional criteria decreases to slightly less than 4.0, while at a higher 250-cms river flow, the chronic dilution factor increases to 4.7.

Outfall 003 Mixing Zone for TSS

The dilution factors provided in Table 2.3-6 were based on model runs using a conservative tracer. This approach underestimates the available dilution associated with a substance whose water column concentration is influenced by settling. This reduction in water column concentration could be of importance when making comparisons to surface water quality criteria for parameters such as total aluminum. The 153-cms model scenario executed in the previous section for a conservative tracer was also executed in SED2D for a 10,000 mg/L, 3.5 hour, clean-out event. The resulting TSS concentrations from combining the sand, floc, and silt particle classes were used to calculate plume widths, cross-sectional areas, and 1-hour average exposure concentrations. The resulting plume dimensions are summarized in the following table.

Dimensions for a TSS Plume, 153-cms River Flow

Dilution	Width		Cross-Section	
	(m)	(%)	(m^2)	(%)
20	9.6	5.5	37.4	3.2
25	22.5	12.8	85.9	7.3
30	29.7	16.9	112	9.5
35	34.5	19.6	130	11.0
40	38.5	21.9	142	12.1
50	44.2	25.1	162	13.7

For a 10-percent cross-sectional area criteria associated with a chronic mixing zone, the allowed dilution factor increased from 4.3 for a conservative tracer (Table 2.3-6) to 31.6 based on TSS and including settling. The acute dilution factor associated with a 1-hour average exposure time increased to 8.1 for the TSS plume.

Alternative Outfall 003 Location

The dilution available at Outfall 003 is limited by it's shoreline location, which impedes mixing with the Potomac River flow beyond the shallower shore zone. To illustrate an alternate Outfall 003 location, the Aqueduct model was executed with the discharge placed off shore. For this example, rather than modeling an actual discharge structure, an equivalent mass loading was added to a model element approximately 200-m in front of the existing shoreline Outfall. At this location, the MLW Potomac River depth was approximately 2 m. A 1.138-cms discharge flow coupled with a 10,000 mg/L TSS concentration results in a mass loading of 11.38 kg/sec. This mass loading was applied to the 200-m offshore model element for a 3.5 hour period during the 153-cms river flow, ebb tide scenario. The resulting plume for a conservative tracer at the end of the 3.5-hour discharge event was processed for plume dimensions and 1-hour average exposure concentrations. A dilution factor for a chronic mixing zone based upon a 10-percent cross-sectional area criteria was 18.6, and a dilution factor for an acute mixing zone based upon a 1-hour average exposure period was 8.4.

2.3.4 Effluent Fate and Transport Modeling Summary

Per an EPA-approved Study Plan (24 June 1999), a hydrodynamic model of the Potomac River was developed to simulate the discharge from Washington Aqueduct outfalls to determine acute and chronic dilution factors and to examine the fate of released solids as they travel downstream. The modeling used the Surfacewater Modeling System (SMS) which includes the U.S. Army

COE – supported models RMA2, RMA4, and SED2D. The model extended 8.0 km from Outfall 002, upstream of Chain Bridge, downstream to below Roosevelt Island and contained a total of 2,021 elements and 6,281 nodes. The field studies used for model calibration and model results for mixing zone and deposition issues are summarized below.

- A bathymetry survey was performed along a total of 46 transects to provide channel geometry for the model.

- Plume mapping studies were conducted at Outfall 002 (Dalecarlia Basin) and Outfall 003 (Georgetown Reservoir). At each outfall, a dye-tracer study was performed on the day the reservoir was being drawn down, and a turbidity study was performed the following day during a solids clean-out event.

- At Outfall 002, 22 percent of the total mass discharged passed beyond the downstream end of the model during a 24-hr run. The resulting depositional footprint estimated using the SED2D model was 1-mm thick in the vicinity of the Outfall 002 and decreased to approximately 0.02 mm downstream in the vicinity of Roosevelt Island.

- At Outfall 003, 13 percent of the total mass discharged passed beyond the downstream end of the model during a 24-hr run. SED2D indicated that the resulting depositional footprint typically exceeded 1 mm in the first 350 m, exceeded 0.2 mm for 2,500 m along the shallow near-shore region downstream, and decreased to approximately 0.05 mm in the vicinity of Roosevelt Island.

- A chronic mixing zone at Outfall 002 (at the permitted river flow of 153 cms) is limited by the 10 % cross-section criterion at a dilution factor of 51. Using the 1-hr float time approach, the acute dilution factor is calculated to be 169.

- At Outfall 003 (Georgetown Reservoir) the chronic mixing zone is limited by the 10% cross-section criterion at a dilution factor of 4.3. The 1-hr average exposure associated with acute criterion results in a dilution factor of 2.33.

- At Outfall 003, acute and chronic dilution factors increase when calculated using TSS rather than a conservative dye tracer. The resulting chromic mixing zone dilution factor was 31.6 and the acute dilution factor (1-hour average exposure) was 8.1.

- Relocation of Outfall 003 a distance 200-m offshore resulted in an acute (1-hour average exposure) dilution factor of 8.4 and a chronic (10% cross-section) dilution factor of 18.6 (conservative dye tracer).

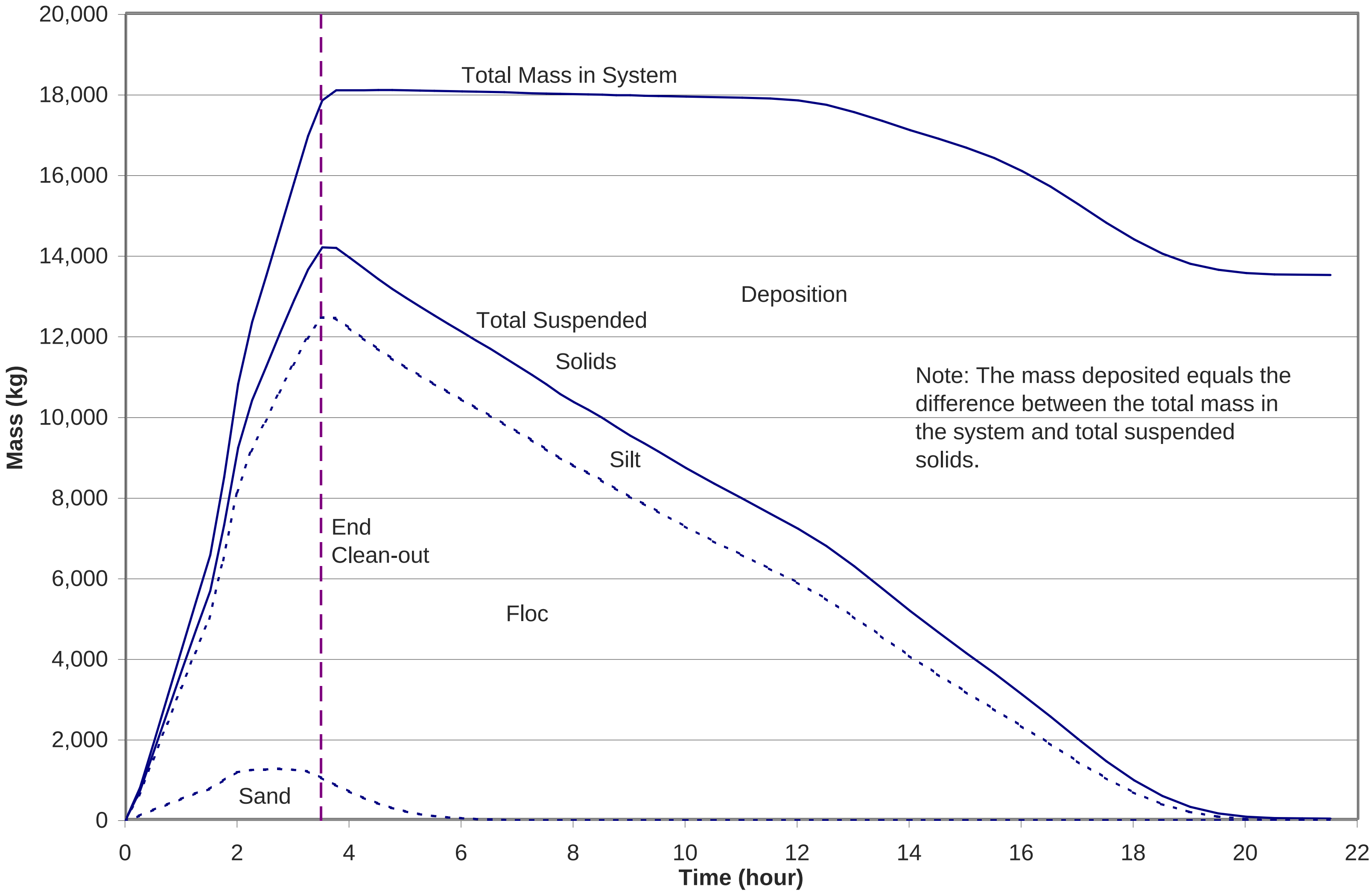
2.4 REFERENCES

Sanford, L.P., W. Panageotou, and J.P. Halka. 1991. Tidal resuspension of sediments in northern Chesapeake Bay. *Marine Geology* 97:87-103.

Tambo, Norihito, and Yoshimasa Watanabe. 1979. Physical characteristics of flocs-1. The Floc Density Function and Aluminum Floc, *Water Research,* Vol. 13:409-419.

Teeter, Allen M., and E. Clark McNair, Jr. 1993. *Size Dependence in Fine-Grained Sediment Transport, Dredging Research Technical Notes*. DRP-1-11. U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS.

Figure 2.3-1 The Incremental Mass Associated with Suspended Sand, Floc, and Silt, the Mass Deposited, and the Total Mass in the System, 25 May 2000, Outfall 002



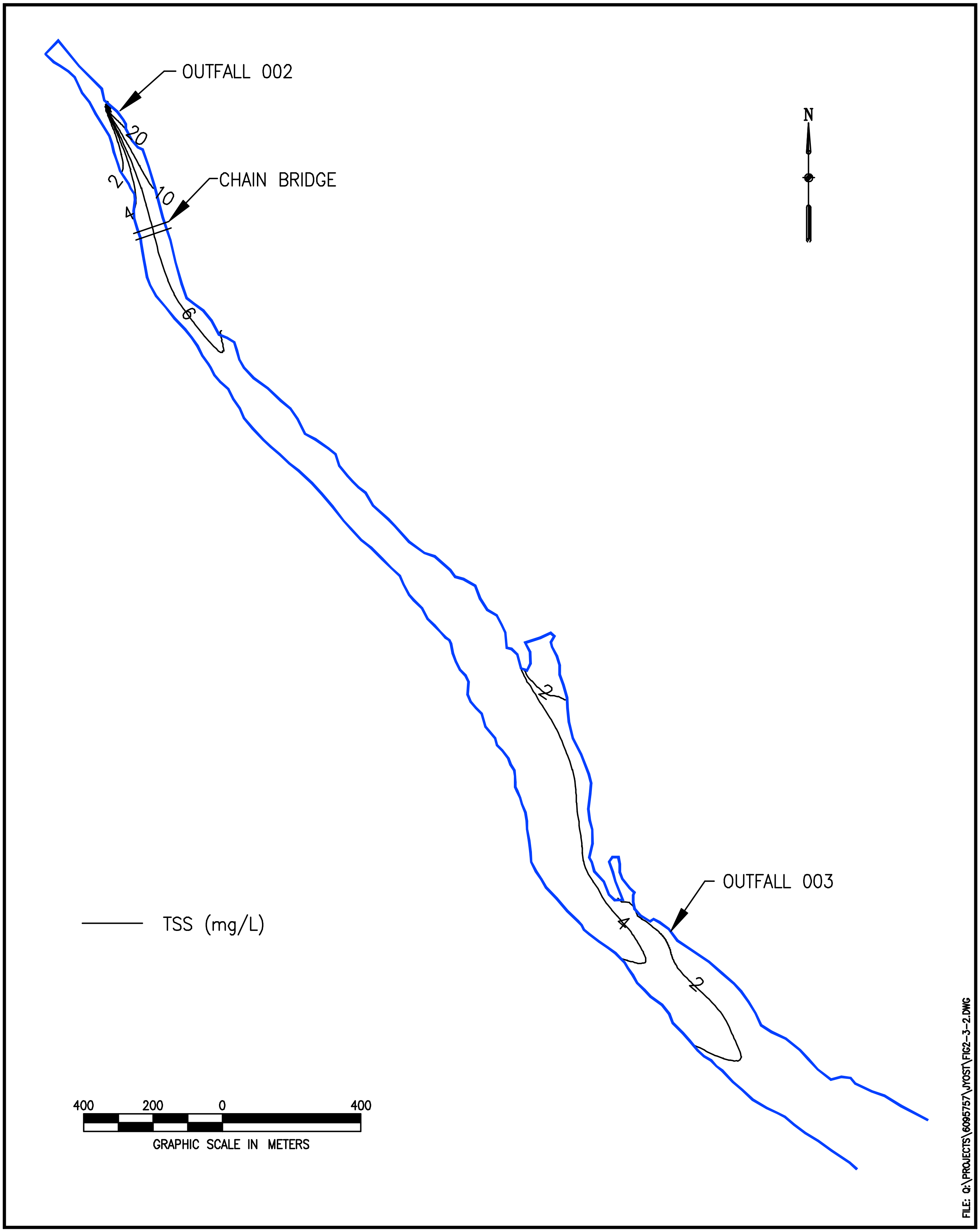


Figure 2.3-2. Predicted TSS Concentrations in the Potomac River at the End of the Solids Release From Outfall 002, 25 May 2000

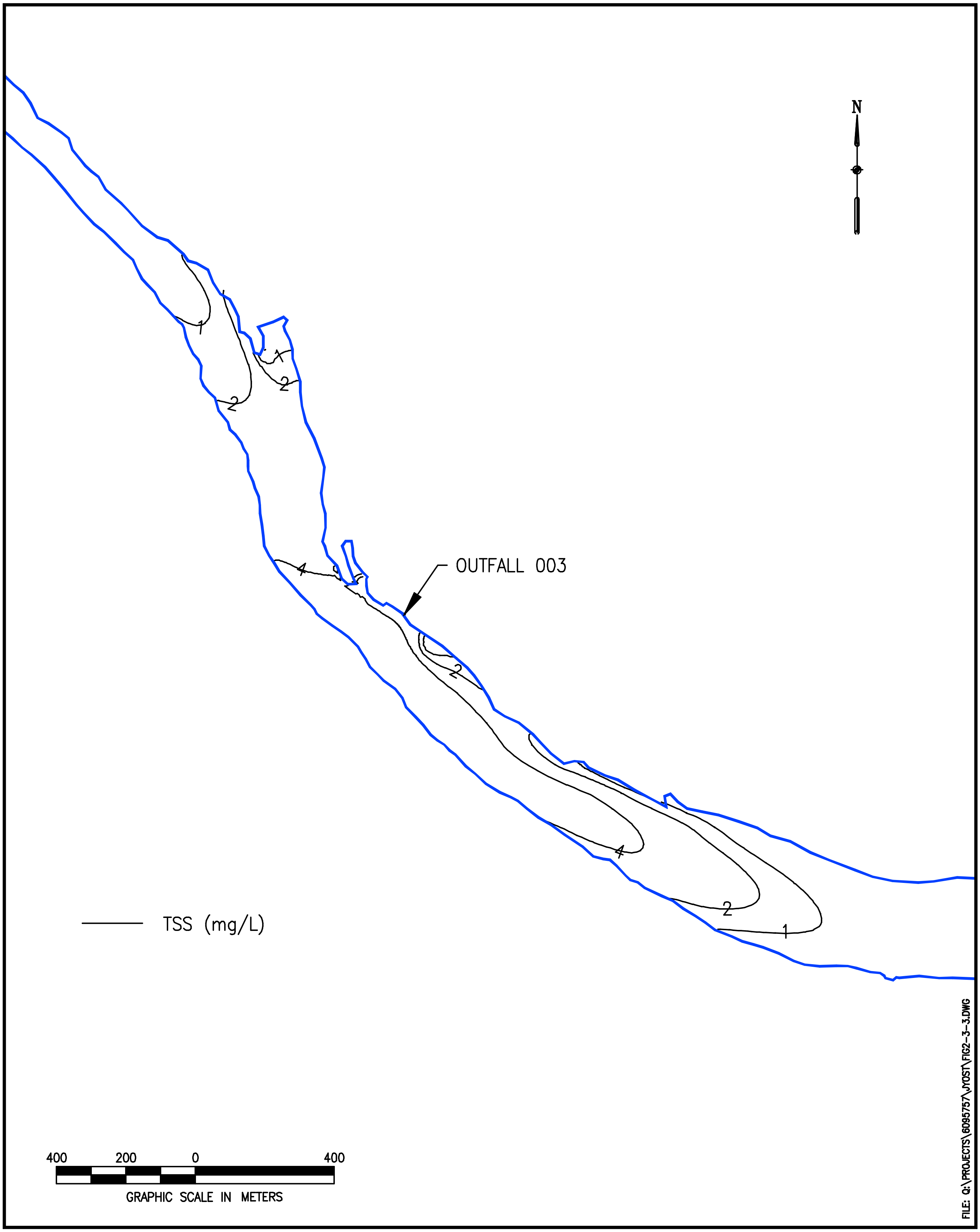


Figure 2.3-3. Predicted TSS Concentrations in the Potomac River 2 Hours After the End of the Solids Release From Outfall 002, 25 May 2000

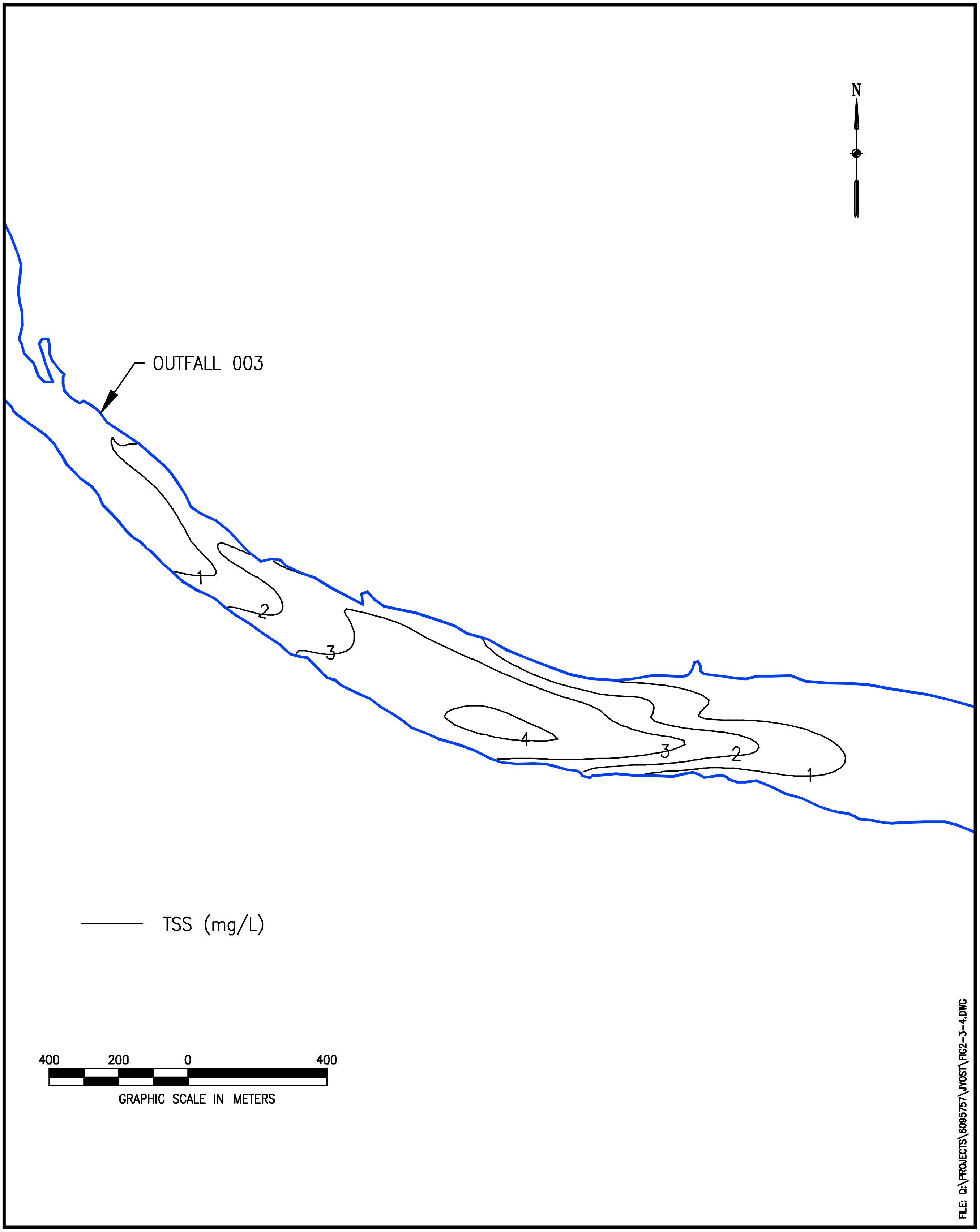


Figure 2.3-4. Predicted TSS Concentrations in the Potomac River
4 Hours After the End of the Solids Release From Outfall 002, 25 May 2000

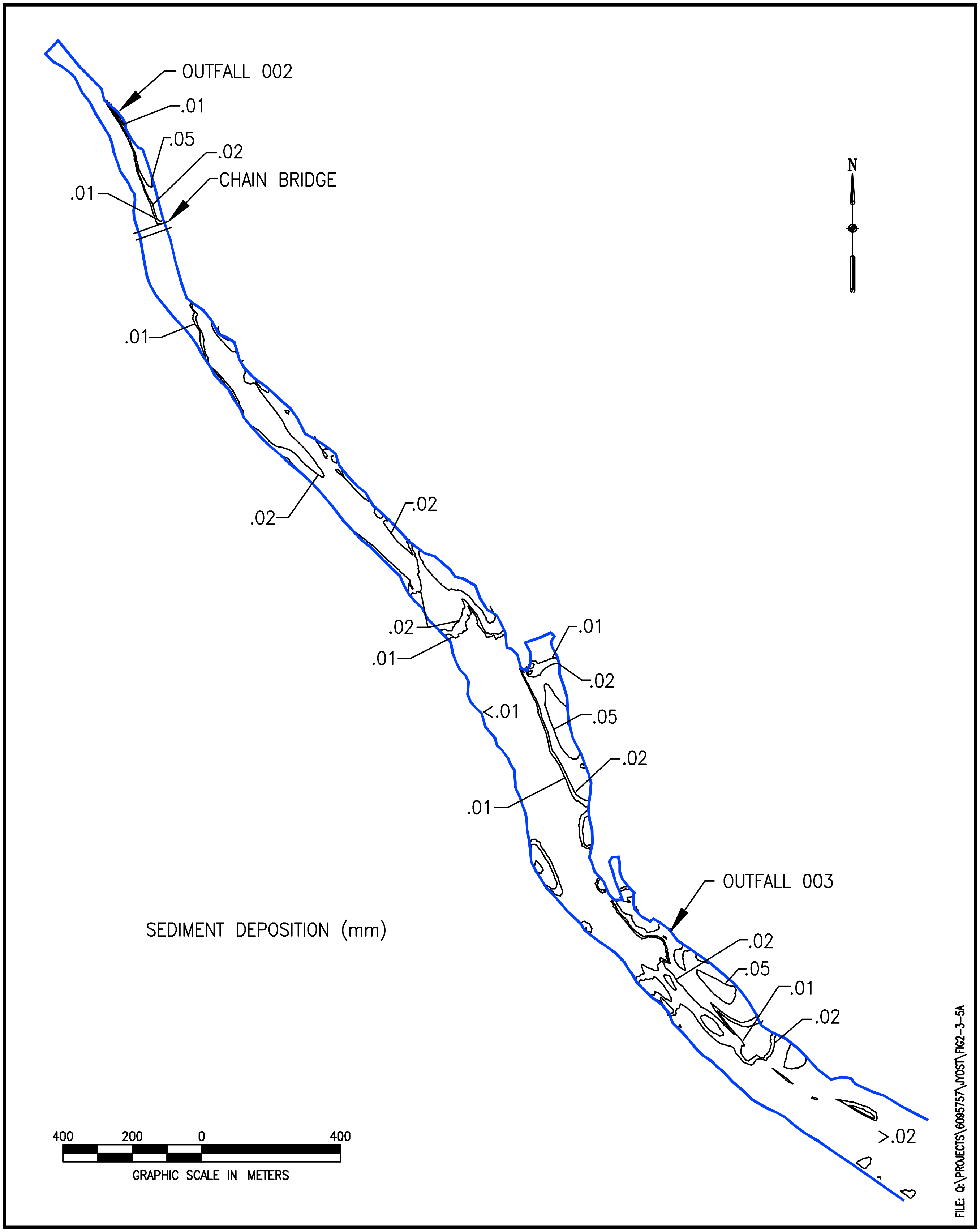


Figure 2.3-5A. Predicted Sediment Deposition Associated with a Clean-Out Event at Outfall 002, 25 May 2000, Upstream

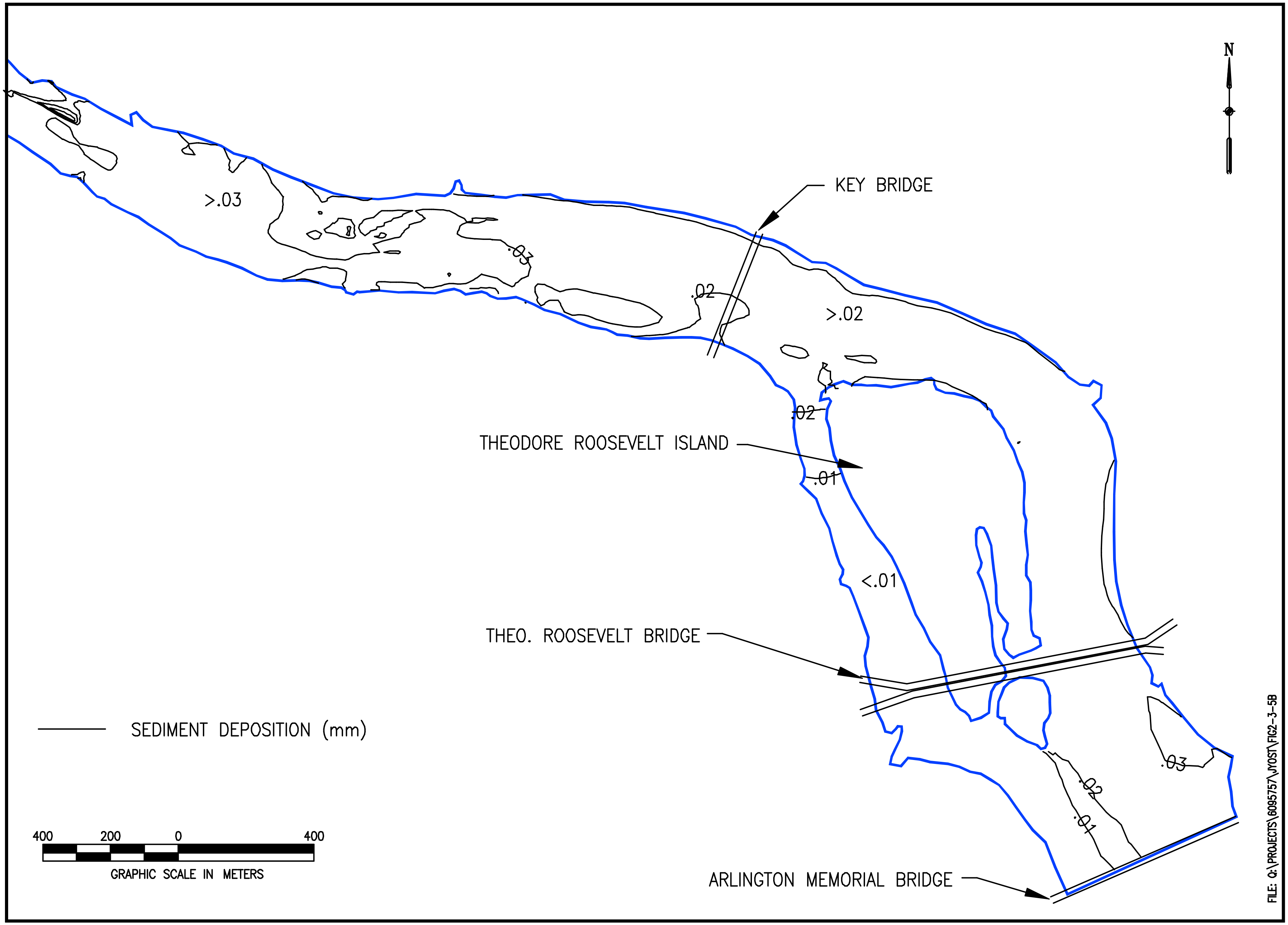
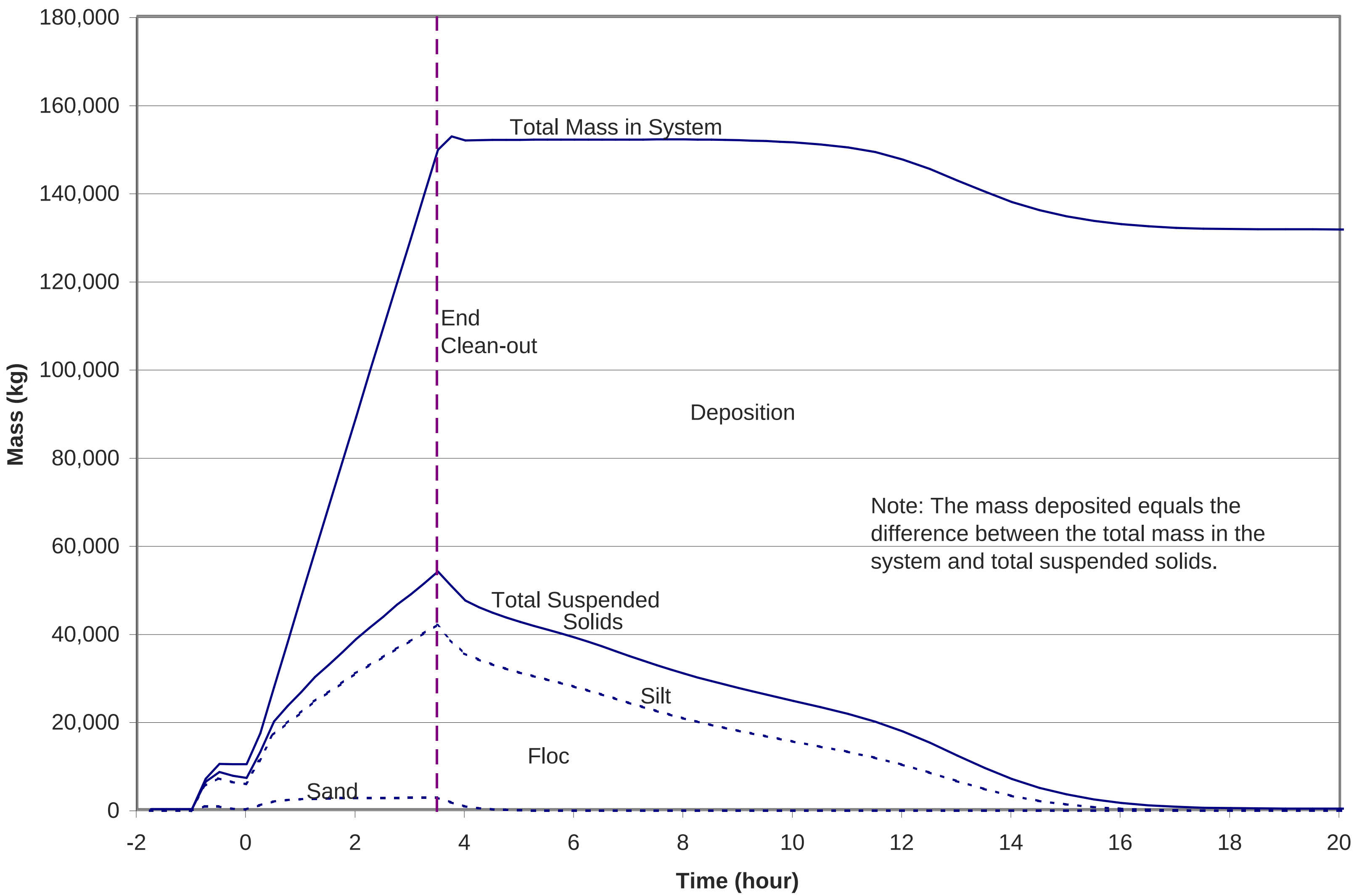


Figure 2.3-5B. Predicted Sediment Deposition Associated With a Clean-Out Event at Outfall 002, 25 May 2000, Downstream

Figure 2.3-6 The Incremental Mass Associated with Suspended Sand, Floc, and Silt, the Mass Deposited, and the Total Mass in the System, 3 May 2000, Outfall 003 Mass



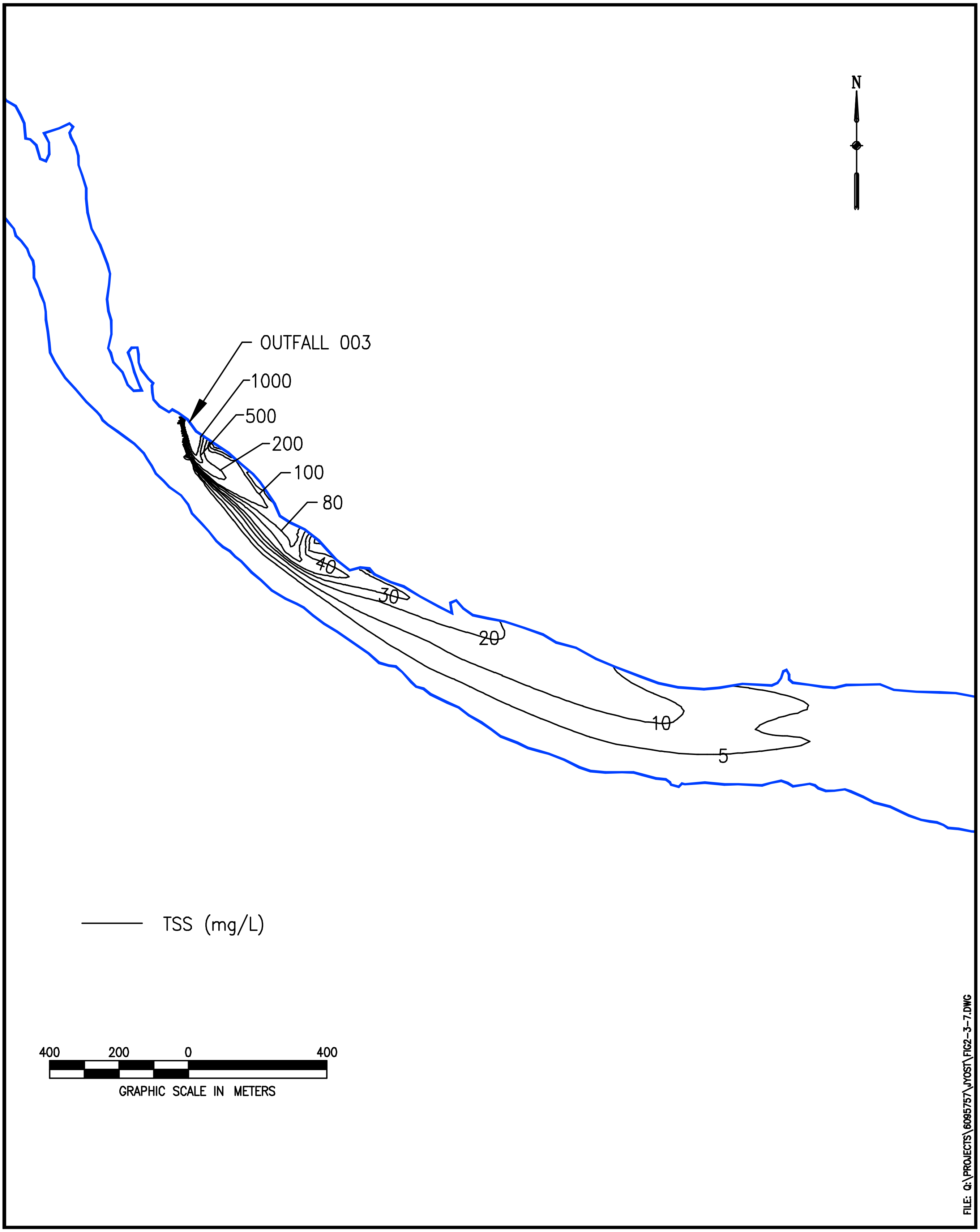


Figure 2.3–7. Predicted TSS Concentrations in the Potomac River at the End of the Solids Release From Outfall 003, 3 May 2000

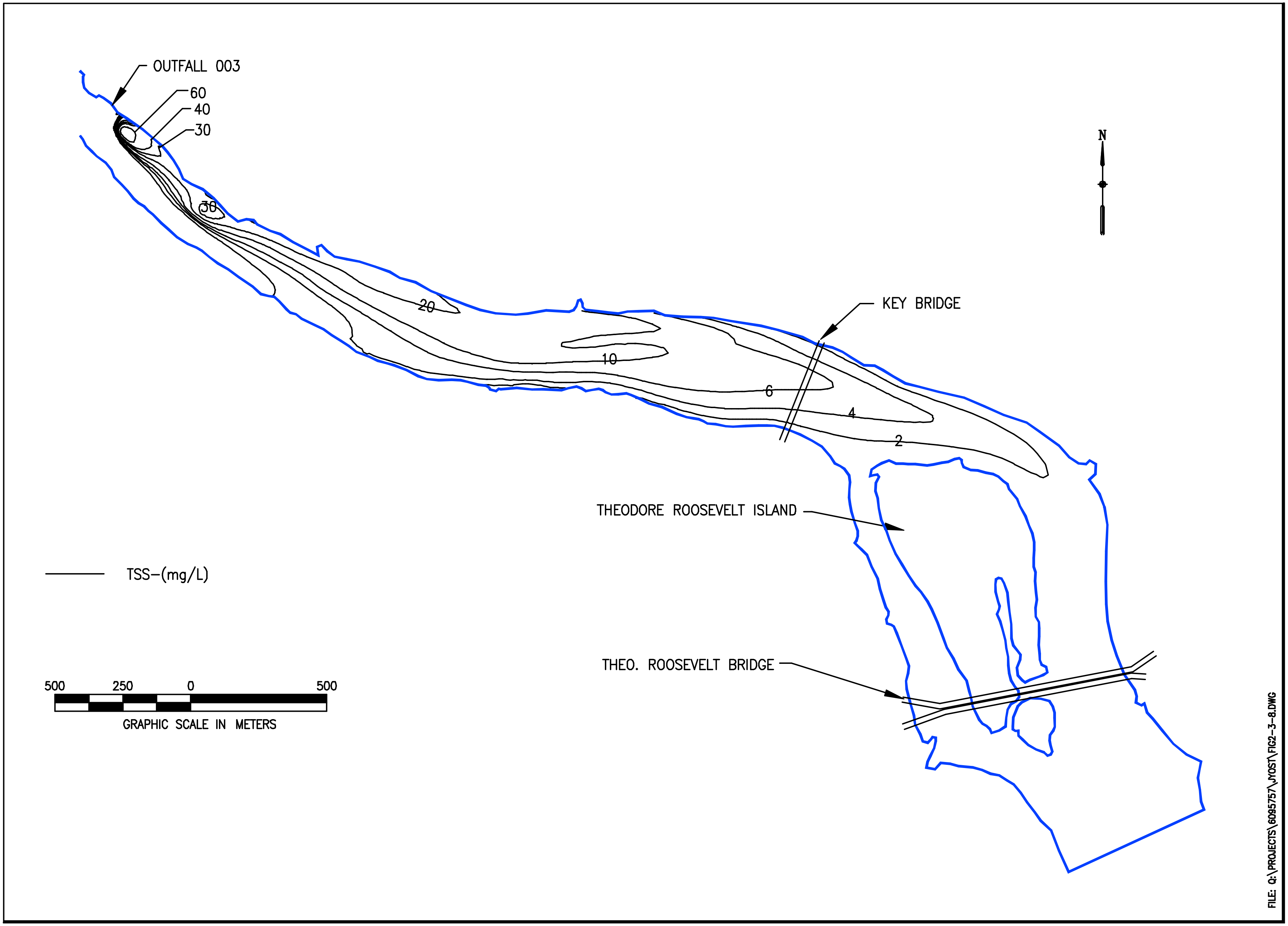


Figure 2.3–8. Predicted TSS Concentrations in the Potomac River 2 Hours After the End of the Solids Release From Outfall 003, 3 May 2000

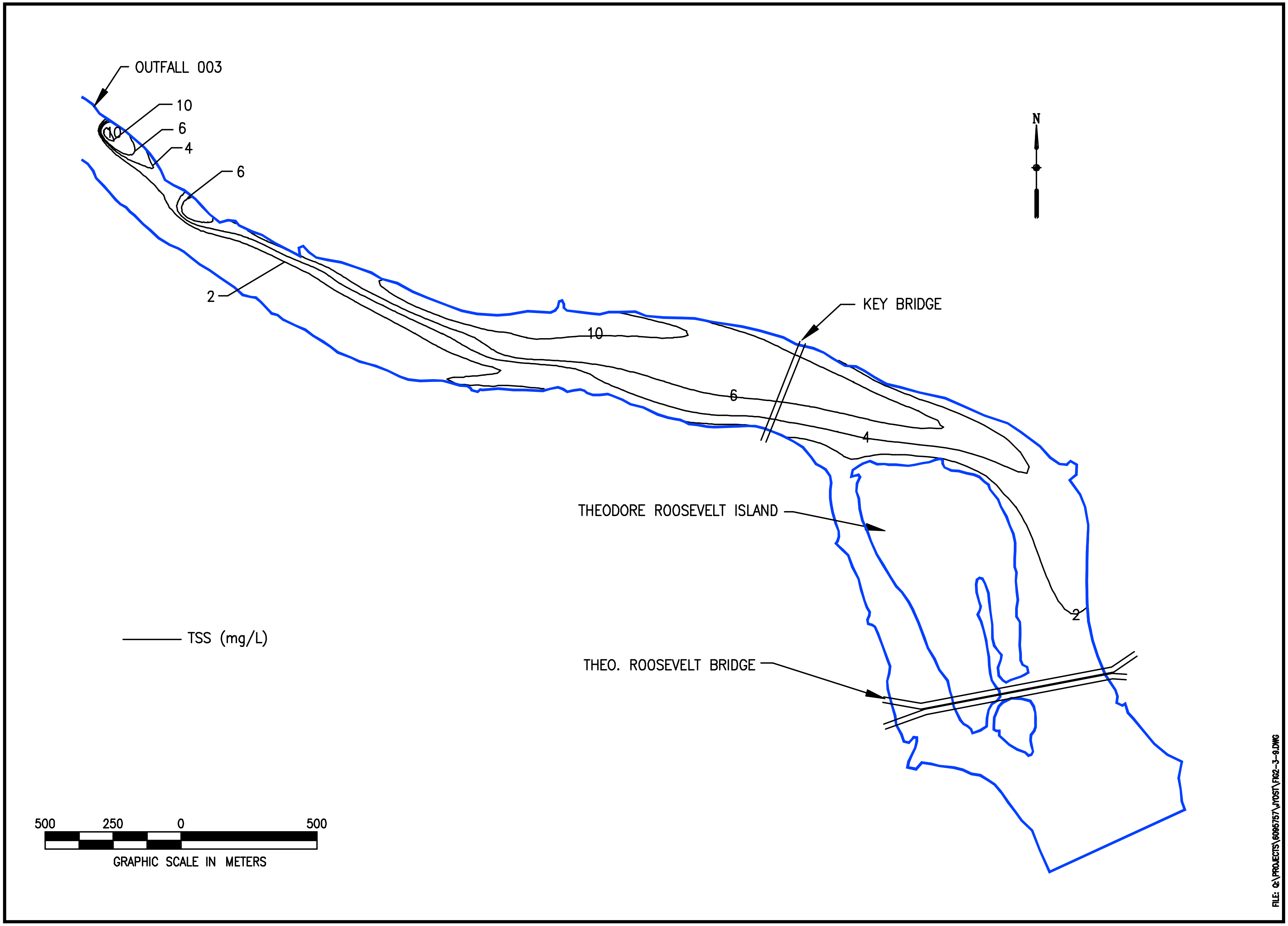


Figure 2.3-9. Predicted TSS Concentrations in the Potomac River 4 Hours After the End of the Solids Release From Outfall 003, 3 May 2000

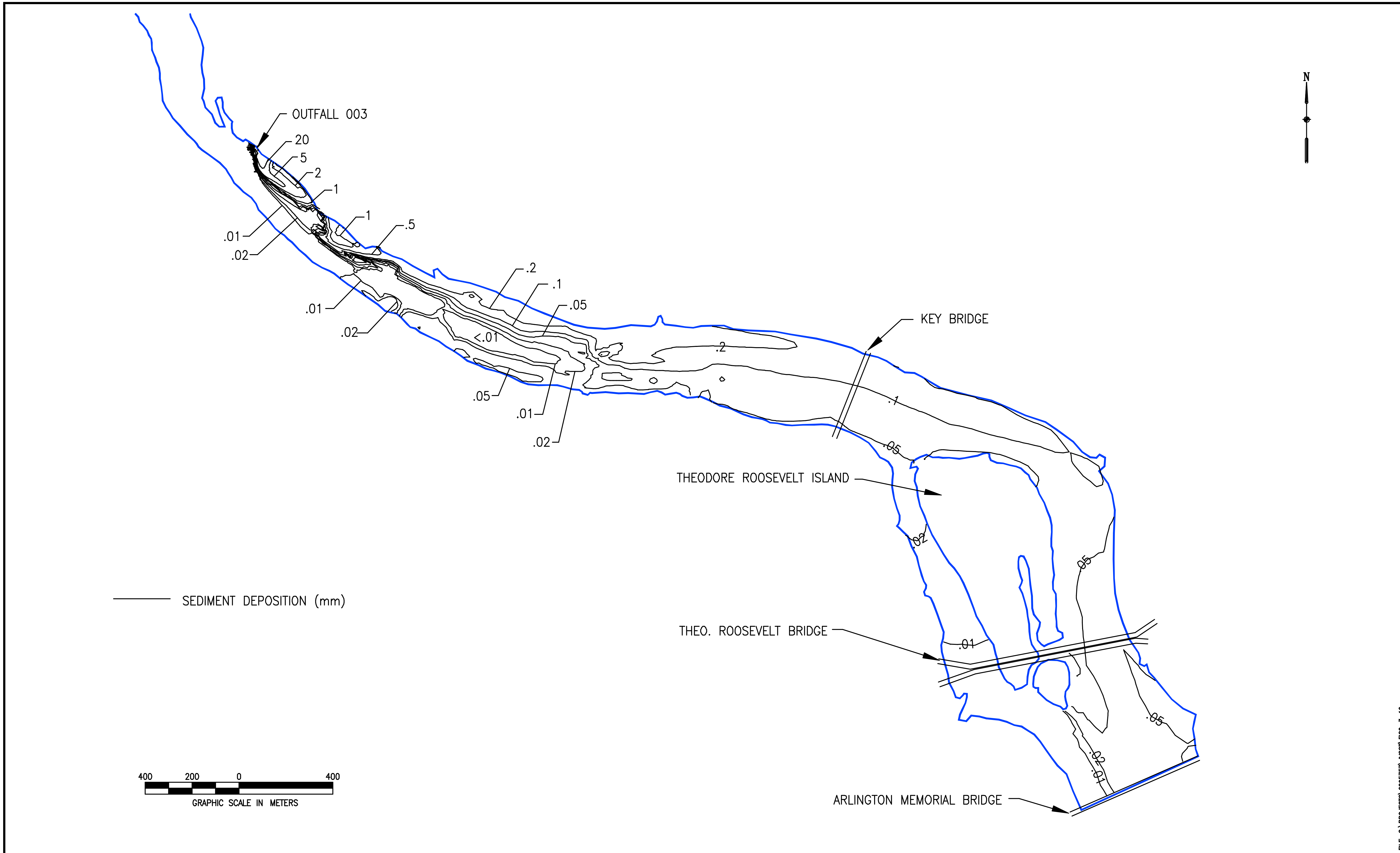


Figure 2.3-10. Predicted Sediment Deposition Associated With a Clean-Out Event at Outfall 003, 3 May 2000

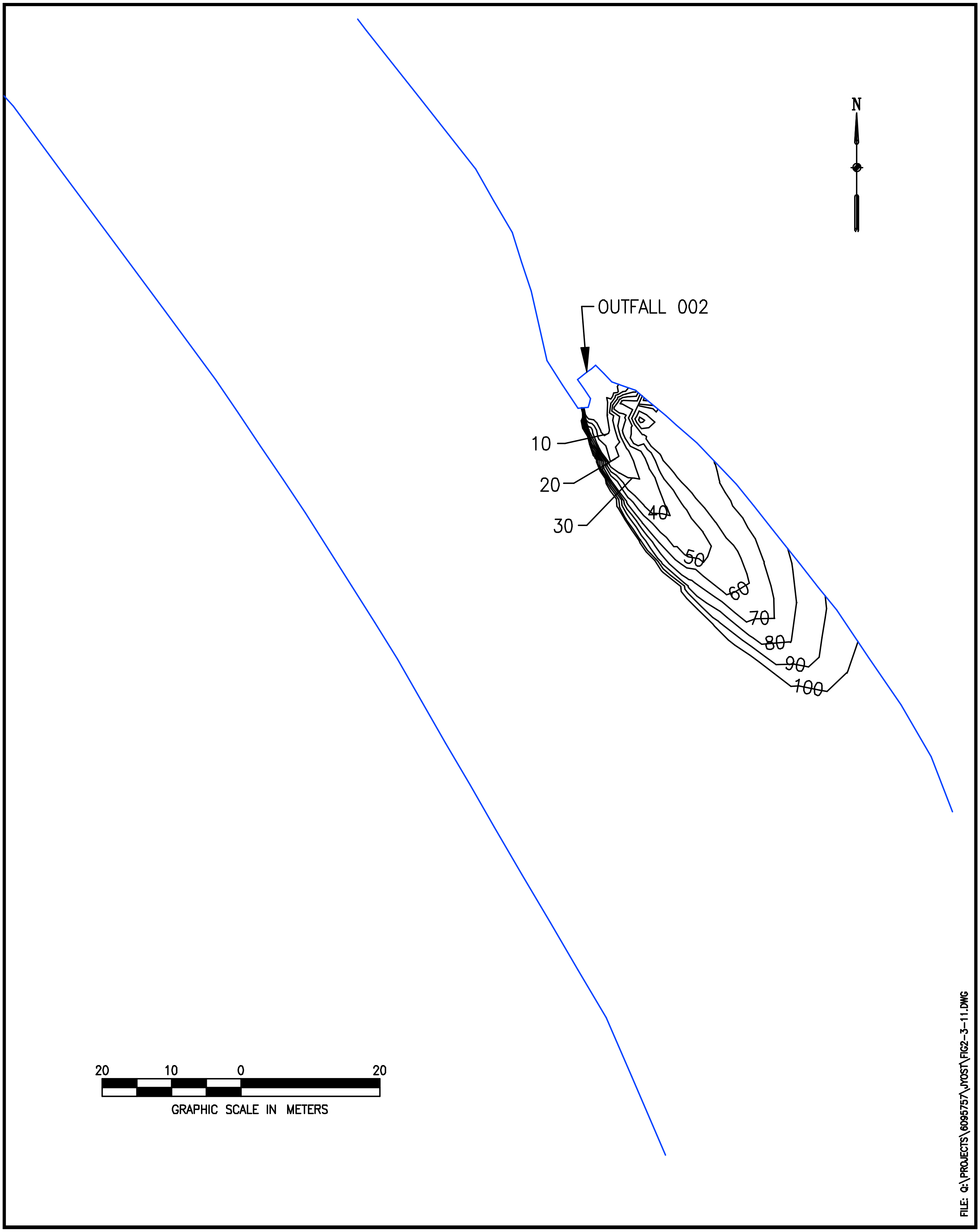


Figure 2.3-11. Predicted Dilution Contours at Outfall 002, 1.132-cms Discharge Flow, 153-cms River Flow

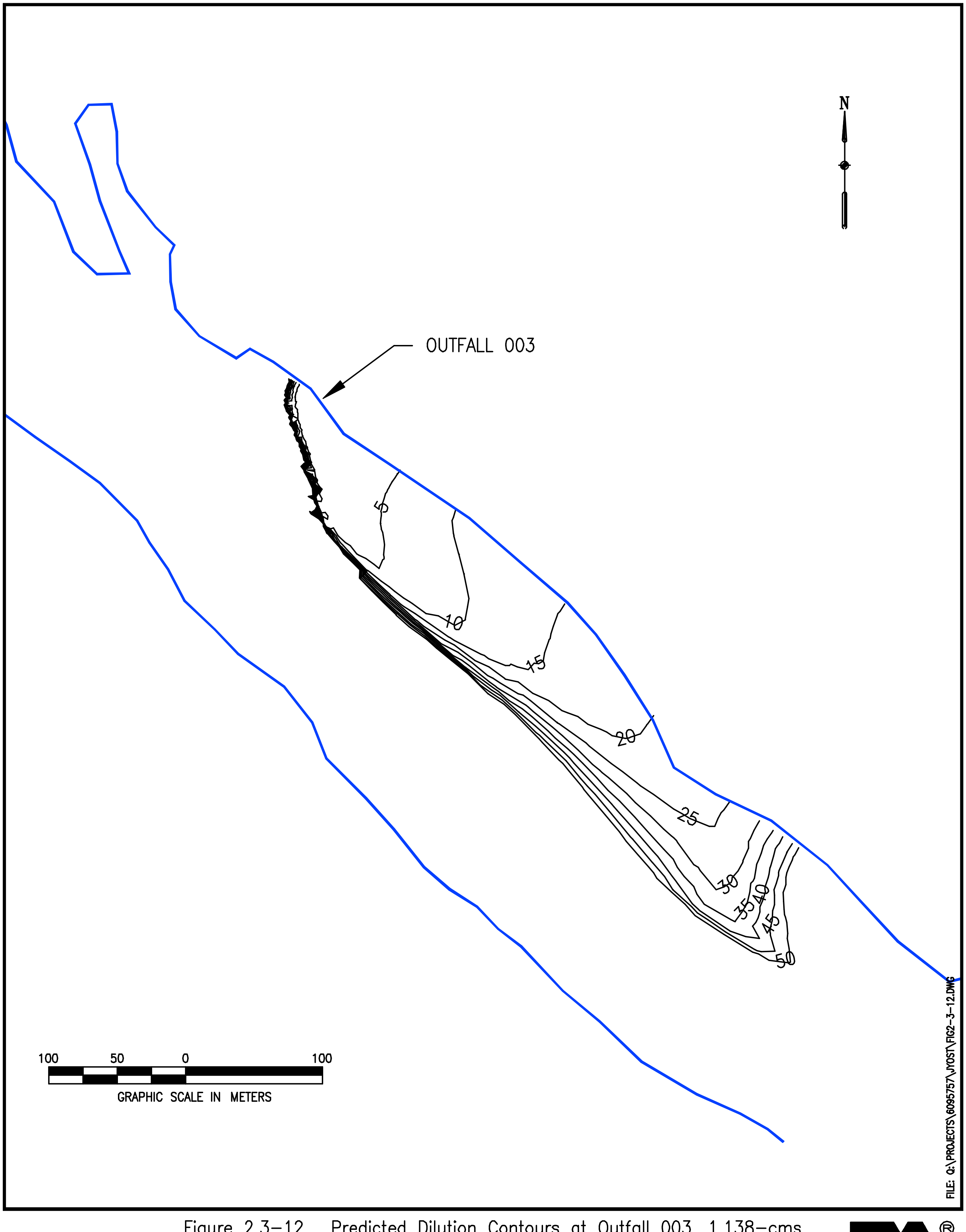


Figure 2.3-12. Predicted Dilution Contours at Outfall 003, 1.138-cms Discharge Flow, 153-cms River Flow

Table 2.3-1 Suspended and Deposited Solids Mass for the Sand, Floc, and Silt Particle Classes Present in the Aqueduct Model Domain, 25 May 2000, Outfall 002

	Mass (kg)								
	Sand		Floc		Silt		Total		
Hour	Suspend	Deposit	Suspend	Deposit	Suspend	Deposit	Suspend	Deposit	Total
0.00	0	0	0	0	0	0	0	0	0
0.25	116	78	506	0	77	0	699	78	777
0.50	262	222	1,256	2	192	0	1,709	224	1,934
0.75	397	376	2,003	6	306	0	2,706	382	3,088
1.0	538	526	2,748	11	420	1	3,706	537	4,242
1.5	781	861	4,228	28	648	1	5,657	891	6,548
2.0	1,198	1,509	6,947	65	1,068	3	9,212	1,577	10,790
2.5	1,270	2,116	8,622	131	1,331	6	11,223	2,253	13,476
3.0	1,260	2,705	10,051	207	1,557	9	12,868	2,922	15,790
3.5	1,066	3,286	11,412	343	1,701	16	14,179	3,645	17,823
4.0	723	3,637	11,502	496	1,690	23	13,915	4,157	18,072
5.0	231	4,150	11,029	960	1,663	46	12,924	5,155	18,079
6.0	59	4,309	10,390	1,590	1,625	78	12,074	5,976	18,050
7.0	10	4,340	9,645	2,328	1,577	116	11,232	6,784	18,015
8.0	0	4,341	8,813	3,147	1,521	161	10,334	7,648	17,982
9.0	0	4,341	8,048	3,895	1,464	203	9,512	8,439	17,951
10.0	0	4,341	7,296	4,632	1,405	248	8,701	9,220	17,921
11.0	0	4,341	6,599	5,315	1,348	292	7,947	9,947	17,894
12.0	0	4,341	5,908	5,947	1,293	334	7,201	10,621	17,822
13.0	0	4,341	5,069	6,545	1,201	379	6,271	11,264	17,535
14.0	0	4,341	4,096	7,162	1,059	428	5,155	11,930	17,085
15.0	0	4,341	3,203	7,721	912	476	4,115	12,537	16,652
16.0	0	4,341	2,351	8,127	732	515	3,083	12,983	16,066
17.0	0	4,341	1,480	8,386	498	542	1,979	13,269	15,248
18.0	0	4,341	702	8,519	255	558	957	13,418	14,374
19.0	0	4,341	218	8,567	83	565	300	13,473	13,773
20.0	0	4,341	38	8,579	17	568	55	13,487	13,542
21.0	0	4,341	2	8,581	9	569	10	13,491	13,501
21.5	0	4,341	0	8,581	5	570	6	13,491	13,497

Note: Clean-out event from 0 to 3.5 hours.

Table 2.3-2 Suspended and Deposited Solids Mass for the Sand, Floc, and Silt Particle Classes Present in the Aqueduct Model Domain over Time, 3 May 2000, Outfall 003

	Mass (kg)								
	Sand		Floc		Silt		Total		
Hour	Suspend	Deposit	Suspend	Deposit	Suspend	Deposit	Suspend	Deposit	Total
-1.00	0	0	0	0	0	0	0	0	0
-0.75	1,056	670	4,493	0	691	0	6,240	670	6,910
-0.50	1,002	1,555	6,385	306	1,017	11	8,403	1,872	10,275
-0.25	519	2,023	6,023	612	999	25	7,541	2,659	10,200
0.00	297	2,240	5,782	843	986	36	7,065	3,118	10,183
0.25	1,211	3,081	10,099	1,127	1,679	49	12,989	4,257	17,246
0.50	2,069	4,801	15,152	2,861	2,671	102	19,892	7,765	27,656
1.0	2,629	9,333	19,562	11,813	4,394	451	26,585	21,597	48,181
1.5	2,812	14,214	23,961	20,729	5,953	951	32,726	35,893	68,619
2.0	2,892	19,189	28,229	29,724	7,474	1,484	38,595	50,396	88,991
2.5	2,932	24,191	31,796	39,325	8,936	2,065	43,664	65,581	109,245
3.0	2,963	29,202	35,420	48,773	10,366	2,670	48,749	80,645	129,393
3.5	2,995	34,216	39,164	58,130	11,775	3,295	53,934	95,641	149,575
4.0	1,008	36,932	34,719	63,748	11,569	3,784	47,296	104,463	151,759
5.0	138	37,783	31,266	67,331	11,108	4,242	42,511	109,356	151,867
6.0	12	37,894	28,228	70,441	10,703	4,645	38,942	112,980	151,922
7.0	0	37,905	24,539	74,144	10,213	5,130	34,752	117,180	151,931
8.0	0	37,909	21,034	77,666	9,720	5,626	30,754	121,200	151,954
9.0	0	37,912	18,217	80,343	9,265	6,046	27,483	124,301	151,783
10.0	0	37,914	15,778	82,406	8,791	6,403	24,569	126,722	151,291
11.0	0	37,914	13,418	83,952	8,184	6,697	21,602	128,562	150,164
12.0	0	37,914	10,532	84,953	7,113	6,908	17,645	129,774	147,419
13.0	0	37,914	6,799	85,534	5,330	7,048	12,129	130,496	142,625
14.0	0	37,914	3,436	85,874	3,381	7,148	6,817	130,936	137,753
15.0	0	37,914	1,450	86,056	1,886	7,219	3,336	131,189	134,524
16.0	0	37,914	482	86,138	920	7,266	1,401	131,318	132,719
17.0	0	37,914	101	86,170	430	7,298	531	131,382	131,913
18.0	0	37,914	4	86,177	212	7,319	216	131,410	131,626
19.0	0	37,914	0	86,178	141	7,336	141	131,427	131,568
20.0	0	37,914	0	86,178	101	7,348	101	131,439	131,540
21.0	0	37,914	0	86,178	61	7,358	61	131,449	131,510
22.0	0	37,914	0	86,178	30	7,362	30	131,454	131,484

Note: Clean-out event from 0 to 3.5 hours with a prerelease.

Table 2.3-3 Downstream Distance to Dilution Contours and 1-Hour Average Dilution at Outfall 002 for a Range of Potomac River Flows, Dalecarlia Basin

Downstream Distance (m) to Dilution Contour for Range of River Flows

	Ebb Tide			Flood Tide		
Dilution	100 cms	153 cms	250 cms	100 cms	153 cms	250 cms
10	7.4	6.4	3.3	6.3	5.9	4.2
20	11.8	9.9	6.1	11.4	8.1	6.4
30	21.7	13.8	7.7	18.9	9.2	7.9
40	29.3	20.6	9.2	27.3	16.7	10.3
50	36.1	29.1	10.7	32.6	23.0	11.6
60	44.8	35.4	11.8	42.2	29.8	13.2
70	56.2	41.3	13.4	50.5	36.0	16.0
80	63.2	45.7	16.0	58.6	41.4	19.1
90	71.8	50.1	18.4	66.1	45.2	21.9
100	80.5	54.2	21.2	74.0	49.6	24.6

Dilution During 1-Hour Average Exposure

	Ebb Tide			Flood Tide		
	100 cms	153 cms	250 cms	100 cms	153 cms	250 cms
1-Hour	109	169	282	95	156	270
Full Mix	758	1160	1895	759	1160	1895

Note: Outfall 002 flow = 0.132 cms (3 mgd)

Table 2.3-4 Plume Width and Cross-Sectional Area at Transect 3-m Downstream of Outfall 002, Dalecarlia Basin

Dilution	Width		X-S Area	
	(m)	(%)	(m^2)	(%)
River Flow = 100 cms (Ebb Tide)				
10	3.7	7.4	7.5	4.0
15	5.1	10.1	10.0	5.4
20	5.8	11.5	11.4	6.1
25	8.6	17.0	15.9	8.5
30	8.6	17.1	16.1	8.6
35(a)	9.0	17.5	21.4	10.9
40(a)	10.5	20.5	24.4	12.5
45(a)	10.6	20.8	25.0	12.8
50(a)	10.8	21.1	25.4	13.0
River Flow = 153 cms (Ebb Tide)				
10	2.4	4.8	5.1	2.7
15	3.5	6.9	7.3	3.9
20	4.0	8.0	8.4	4.5
25	4.3	8.6	9.0	4.8
30	8.7	17.3	16.3	8.7
35	8.8	17.4	16.4	8.8
40	8.9	17.6	16.6	8.9
45	9.0	17.9	17.1	9.2
50	9.2	18.2	17.5	9.4
60(a)	11.1	21.8	26.8	13.6
River Flow = 250 cms (Ebb Tide)				
10	0.0	0.0	0.0	0.0
15	2.1	4.2	4.3	2.3
20	3.0	5.9	6.0	3.2
25	3.5	6.9	7.1	3.8
30	3.8	7.5	7.8	4.2
35	8.4	16.7	15.6	8.4
40	8.5	16.9	15.9	8.5
45	8.6	17.0	16.1	8.6
50	8.6	17.2	16.2	8.7
60	8.7	17.4	16.5	8.8
80	9.0	17.9	17.1	9.1

Note: Outfall 002 flow = 0.132 cms (3 mgd)
a) 7-m downstream transect.

Table 2.3-5 Downstream Distance to Dilution Contours and 1-Hour Average Dilution at Outfall 003 for a Range of Potomac River Flows, Georgetown Reservoir

Downstream Distance (m) to Dilution Contour for Range of River Flows

Dilution	Ebb Tide			Flood Tide		
	100 cms	153 cms	250 cms	100 cms	153 cms	250 cms
5	136	138	129	123	133	132
10	196	195	176	184	189	179
15	240	240	219	233	236	217
20	293	302	263	274	284	257
25	355	377	341	313	336	310
30	409	439	434	348	385	401
35	444	468	468	376	428	459
40	467	488	493	401	455	483
45	480	504	514	422	473	503
50	492	517	531	437	490	522

Dilution During 1-Hour Average Exposure

	Ebb Tide			Flood Tide		
	100 cms	153 cms	250 cms	100 cms	153 cms	250 cms
1-Hour	2.16	2.33	2.65	2.32	2.31	2.30
Full Mix	89	136	221	89	135	221

Note: Outfall 003 flow = 1.138 cms (26 mgd)

Table 2.3-6 Plume Width and Cross-Sectional Area at a Transect 90-m Downstream of Outfall 003, Georgetown Reservoir

Dilution	Width (m)	Width (%)	X-S Area (m^2)	X-S Area (%)
River Flow = 100 cms (Ebb Tide)				
4	34.4	19.6	120	11.1
5	52.6	29.9	157	14.5
10	70.8	40.3	187	17.3
15	73.5	41.8	203	18.7
20	75.1	42.7	212	19.6
25	76.1	43.2	218	20.1
30	76.7	43.6	221	20.4
35	77.2	43.9	224	20.7
40	77.5	44.0	226	20.9
45	77.8	44.2	227	21.0
50	78.0	44.3	229	21.1
River Flow = 153 cms (Ebb Tide)				
4	26.6	15.1	98	9.1
5	39.5	22.4	134	12.4
10	70.2	39.9	184	17.0
15	71.6	40.7	192	17.7
20	73.5	41.8	203	18.7
25	74.7	42.4	209	19.4
30	75.4	42.9	214	19.8
35	76.0	43.2	217	20.1
40	76.4	43.4	219	20.3
45	76.7	43.6	221	20.4
50	76.9	43.7	223	20.6
River Flow = 250 cms (Ebb Tide)				
4	23.5	13.4	85	7.8
5	34.9	19.9	118	10.9
10	67.5	38.4	170	15.7
15	69.1	39.3	178	16.5
20	69.9	39.7	183	16.9
25	70.4	40.0	185	17.1
30	70.7	40.2	187	17.3
35	71.0	40.3	188	17.4
40	71.1	40.4	189	17.5
45	71.8	40.8	193	17.8
50	72.5	41.2	197	18.2

Note: Outfall 003 flow = 1.138 cms (26 mgd)